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THIS REPORT PRESENTS THE RESULTS OF A PHASE I LITERATURE REVIEW AND SITE RECONNAISSANCE OF AQUATIC RESOURCES AT RMA.

THE PRIMARY PURPOSES OF THE INVESTIGATION ARE TO:

1. CHARACTERIZE THE AQUATIC RESOURCES IN TERMS OF HABITAT, SPECIES COMPOSITION, AND PAST MANAGEMENT RESOURCES
2. ASSESS THE CONTAMINATION HISTORY OF THOSE RESOURCES
3. PROVIDE A BASIS FOR DESIGNING MORE DETAILED PHASE II PROGRAMS.

THE EMPHASIS OF THE STUDY IS TO DOCUMENT INJURIES TO THE AQUATIC RESOURCES RESULTING FROM THE PRODUCTION, STORAGE, AND DISPOSAL OF CHEMICALS AT RMA.

SECTIONS OF THIS REPORT DETAIL INFORMATION ON:

1. AQUATIC RESOURCES
2. FOOD WEBS
3. HISTORY OF FISHERIES MANAGEMENT
4. AQUATIC CONTAMINATION

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PHASE I LITERATURE REVIEW
AQUATIC RESOURCES INVESTIGATION
ROCKY MOUNTAIN ARSENAL

Prepared by
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August 1987

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

This report presents the results of a Phase I literature review and site reconnaissance of aquatic resources at the Rocky Mountain Arsenal near Denver, Colorado. The Phase I investigation was directed by Morrison-Knudsen Engineers (MKE). The primary purposes of the investigation were to (1) characterize the aquatic resources in terms of habitat, species composition, and past management practices, (2) assess the contamination history of those resources, and (3) provide a basis for designing more detailed Phase II field programs.

The emphasis of the Phase I and Phase II studies is on documenting injuries to the aquatic resources resulting from the production, storage, and disposal of chemicals at the site. Data developed during the studies will also be applicable in designing a remediation program for the Arsenal. The Phase I report has been prepared in accordance with U.S. Department of the Interior (DOI) "Final Rules and Regulations Pertaining to Natural Resources Under CERCLA" (43 CFR Part II) and the U.S. Environmental Protection Agency's "Guidance on Remedial Investigations Under CERCLA" (USEPA 1985a).

MKE's Phase I studies roughly correspond with Level I (Problem Identification and Scoping) remedial investigations as described in the EPA's technical guidance document. Phase II studies will correspond with EPA's Level II (Problem Quantification) and Level III (Detailed Investigation) stages of the remedial investigation process.

The major sources of information used in the Phase I literature review were governmental documents from the Rocky Mountain Arsenal, U.S. Fish and Wildlife Service, and Army Corps of Engineers; Shell Oil Company documents; and reports from environmental subcontractors who have conducted studies on the Arsenal. The References section of this report (Section 7.0) lists all of the documents reviewed, whether cited or not, along with document identification numbers when available. Comments on the existing environment at RMA are based on reconnaissance surveys conducted by MKE and its subcontractors in August and October 1985 and June 1986, as well as on existing literature.

2.0 ARSENAL OVERVIEW

2.1 GENERAL HISTORY

The Rocky Mountain Arsenal (RMA) is an Army installation covering about 70 square kilometers (km) (17,250 acres; 27 square miles) in southern Adams County, Colorado, about 16 km northeast of Denver (Fig. 2-1). Before the Arsenal was established, the area was used primarily for rangeland and dryland agriculture, mostly as small farms and ranches. This land use still dominates areas to the north and east of RMA. The small town of Derby was in the vicinity of the area now occupied by the South Lakes.

RMA was originally established in 1942 as a World War II facility for the manufacture of chemical and incendiary munitions. After the war, the Army continued to conduct research and to produce, demilitarize, and store chemical agents at the Arsenal. Also following the war, several of the facilities in the South Plants area of the Arsenal were leased to private chemical manufacturing companies. Starting in 1947, Colorado Fuel and Iron (CF&I) manufactured chlorinated benzenes and dichlorodiphenyltrichloroethane (DDT). Also in 1947, Julius Hyman and Company (Hyman) began production of a variety of pesticides. Hyman assumed the CF&I lease in 1950. In May 1952, Shell assumed the Hyman lease and continued manufacturing pesticides until 1982.

2.2 ENVIRONMENT

2.2.1 Physiography and Topography

The region in which RMA is located has been referred to by Thornbury (1965) and Hunt (1967) as the High Plains Section of the Great Plains Province. The Arsenal lies near the western edge of the High Plains, which grade abruptly into the Southern Rocky Mountain Province approximately 23 km to the west.

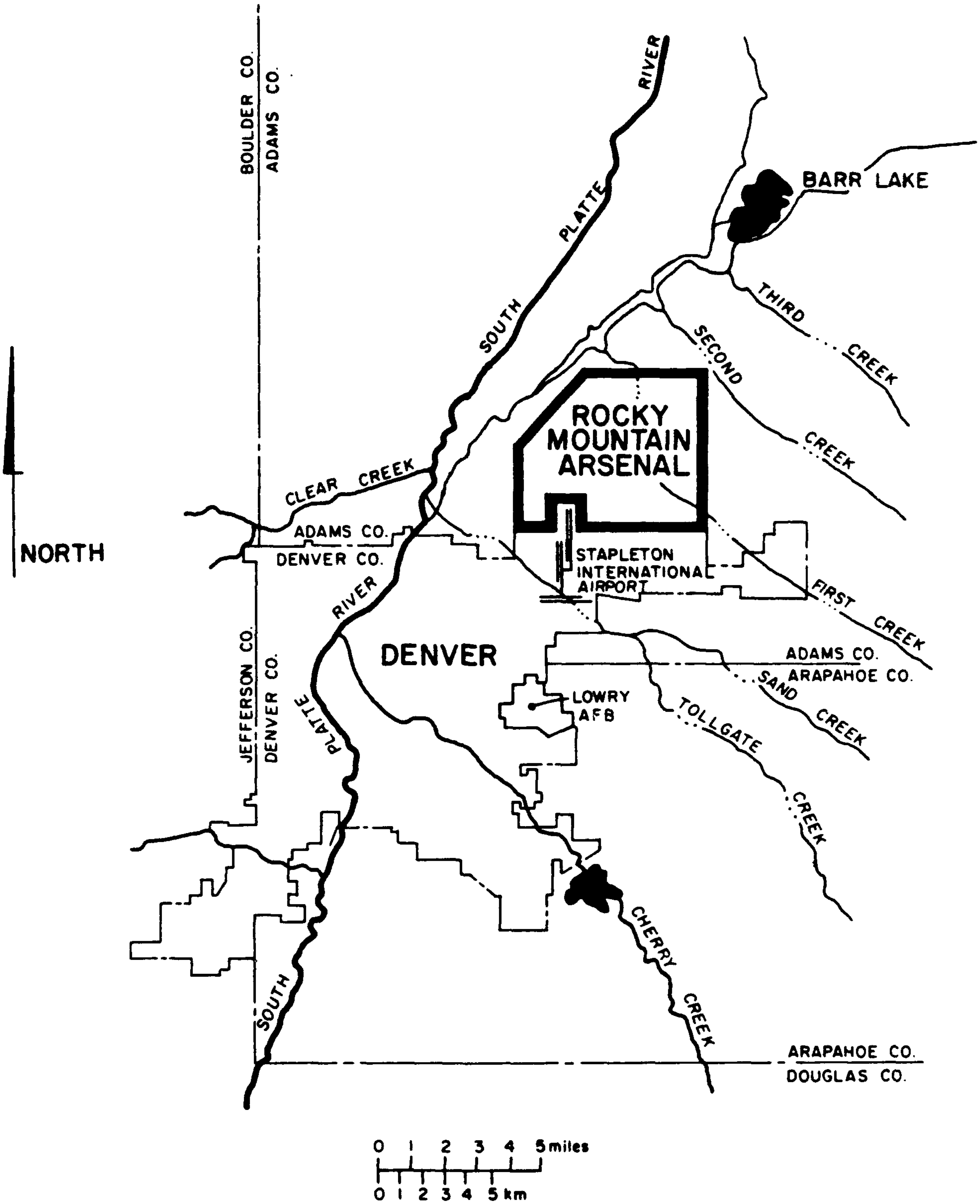

FIGURE 2-1

LOCATION MAP ROCKY MOUNTAIN ARSENAL

The topography of the Arsenal may be characterized as gently rolling with low hills and intervening basins. Elevations range from approximately 1,500 meters (m) in a closed depression along the northwestern boundary to about 1,625 m in the southeastern corner. Other high areas include "Rattlesnake Hill" (about 1,615 m) near the center of the site, and "Henderson Hill" (about 1,600 m) near the northeastern corner. Surface drainages on the Arsenal generally flow from southeast to northwest, toward the South Platte River. These surface drainages are described in detail in Section 3.1.

2.2.2 Geology and Soils

Surficial deposits on the RMA consist of stabilized eolian sand and alluvium composed of sand, silt, and gravel. This surface veneer is generally less than 15 m thick over most of the Arsenal. Greater thicknesses of alluvium overlie paleochannels eroded into the bedrock surface. The alluvium also gradually thickens north and northwest of the site as it approaches the South Platte River. The Cretaceous Denver Formation, consisting of 120-190 m of interbedded shale and weakly indurated lenticular sandstone, underlies the surficial deposits across the entire Arsenal. The surficial alluvium and the Denver Formation are the two aquifers of primary concern at RMA.

Soils of the RMA include three general groupings: (1) clayey soils on nearly level upland surfaces, especially in the northern portion of the site; (2) sandy eolian soils on more rolling upland surfaces, especially in the southern portion of the site; and (3) loamy and sandy stratified alluvial soils on the floodplains and low terraces of major drainages. The soils generally are deep and well drained. Most show clay and, to a lesser extent, lime enrichment in the subsoil.

2.2.3 Climate

The climate of the region is sunny and semi-arid and generally lacks prolonged periods of very cold or very hot weather. The region averages about 30 days with highs above 32°C (90°F) and 150 days with lows below 0°C (32°F) per year and has an average growing season of 180 days.

Mean annual precipitation of the region is about 39 centimeters (cm) (15.5 inches). The wettest season is spring (March - May), which receives about 35 percent of the yearly total as wet snows and steady rains. Precipitation gradually declines through the summer as rainfall becomes more scattered but occasionally intense, then decreases drastically during fall and winter. The winter season (December - February) receives only about 11 percent of the total precipitation, in the form of fairly frequent but very dry snowfalls. Relative humidities are generally low, with monthly averages of about 50-60 percent throughout the year, and with numerous days below 10 percent. The mean maximum and minimum temperatures are about 5°C (41°F) and -11°C (12°F) for January, and 29°C (85°F) and 13°C (55°F) for July.

2.2.4 Biota

The original, pre-settlement vegetation of the Arsenal probably was dominated by various native grassland communities interspersed with stands of shrubs or yucca, and with narrow belts of cottonwoods and willows along drainages. After settlement, most of the area was converted to agricultural uses such as grain and hay production and livestock grazing. These activities resulted in extensive destruction of the native plant cover.

The existing vegetation of the RMA reflects a prolonged period of abuse or neglect, being dominated by three weedy plant communities or vegetation types. These three--referred to by MKE as the weedy forb, cheatgrass/weedy forb, and cheatgrass/perennial grass vegetation types--together comprise about 65 percent of the land area at the Arsenal. All three of the weedy types have probably resulted from past disturbances related to agriculture or the construction and operation of the Arsenal.

In addition to the three weedy vegetation types are stands dominated by crested wheatgrass, an asiatic species widely planted in the 1930s and 1940s to rehabilitate disturbed or overgrazed rangeland. Crested wheatgrass covers about 15 percent of the Arsenal. The remainder of the site includes some areas of native grassland with varying amounts of yucca and shrubs, scattered locust thickets probably initially planted for wildlife cover, riparian and wetland vegetation in moister areas, and a few ornamental plantings.

Riparian and wetland vegetation types occur along the drainages and the ditches or canals that cross the Arsenal, and around the reservoirs and ponds. These types include cottonwood and willow woodlands, especially adjacent to First Creek and the South Lakes, and marsh vegetation--predominantly broadleaf and narrowleaf cattails--around the ponds and shallow arms of the lakes.

The terrestrial wildlife of the Arsenal is typical for the region, including grassland, prairie woodland, and ranchland or farmland species. Total diversity is enhanced considerably by the cover and food base of the riparian woodlands and by the availability of dependable surface waters. Thus, for example, mule and white-tailed deer are abundant on the Arsenal, as are waterfowl during the spring and fall migrations. The aquatic habitats also are utilized by wading birds such as great blue herons and black-crowned night-herons, shorebirds, wintering bald eagles, white pelicans, and muskrats, as well as by amphibians, fish, and aquatic invertebrates.

3.0 AQUATIC RESOURCES OF THE ARSENAL

3.1 NATURAL DRAINAGES

Surface runoff on the Arsenal flows generally northwestward toward the South Platte River, which roughly parallels the northwestern boundary at a distance of about 3.2 km. Drainages and drainage basins on RMA are described in the following subsections and shown in figures 3-1 and 3-2.

3.1.1 First Creek

The largest and most important surface drainage on the Arsenal is First Creek, which drains most of the northeastern half of the site (about 24 km^2) (Fig. 3-1) and has a total length onsite of 9.4 km (Fig. 3-2). First Creek originates in Arapahoe County, Colorado, 32 km east of Denver, and has a total basin area of 106 km^2. It has a maximum discharge capacity of 7 cubic meters per second where it enters the southeastern corner of the Arsenal in Section 8, and 8.5 cubic meters per second as it exits at the northern perimeter in Section 24 (U.S. Army 1983a). Its average gradient across the site is 4.9 m/km. The average width of the First Creek channel within the Arsenal is 3 m, and the depth from the top of the bank ranges from 0.6 to 1.8 m. In dry years, the flow of First Creek on the Arsenal is continuous only during the spring and following major storms, but it generally may be characterized as a fairly persistent intermittent stream. The persistence of flow is evidenced by well-developed hydrophytic and phreatophytic vegetation along much of its length.

Onsite contribution to First Creek include several canals and ditches. Aerial photographs taken in 1956 show a ditch connecting the northern end of the Toxic Storage Yard with First Creek; this ditch was not apparent in the aerial photographs from 1948. A visit to the site in June 1986 revealed that the northern end of Sand Creek Lateral presently drains portions of the North Plants and flows into First Creek. This connection

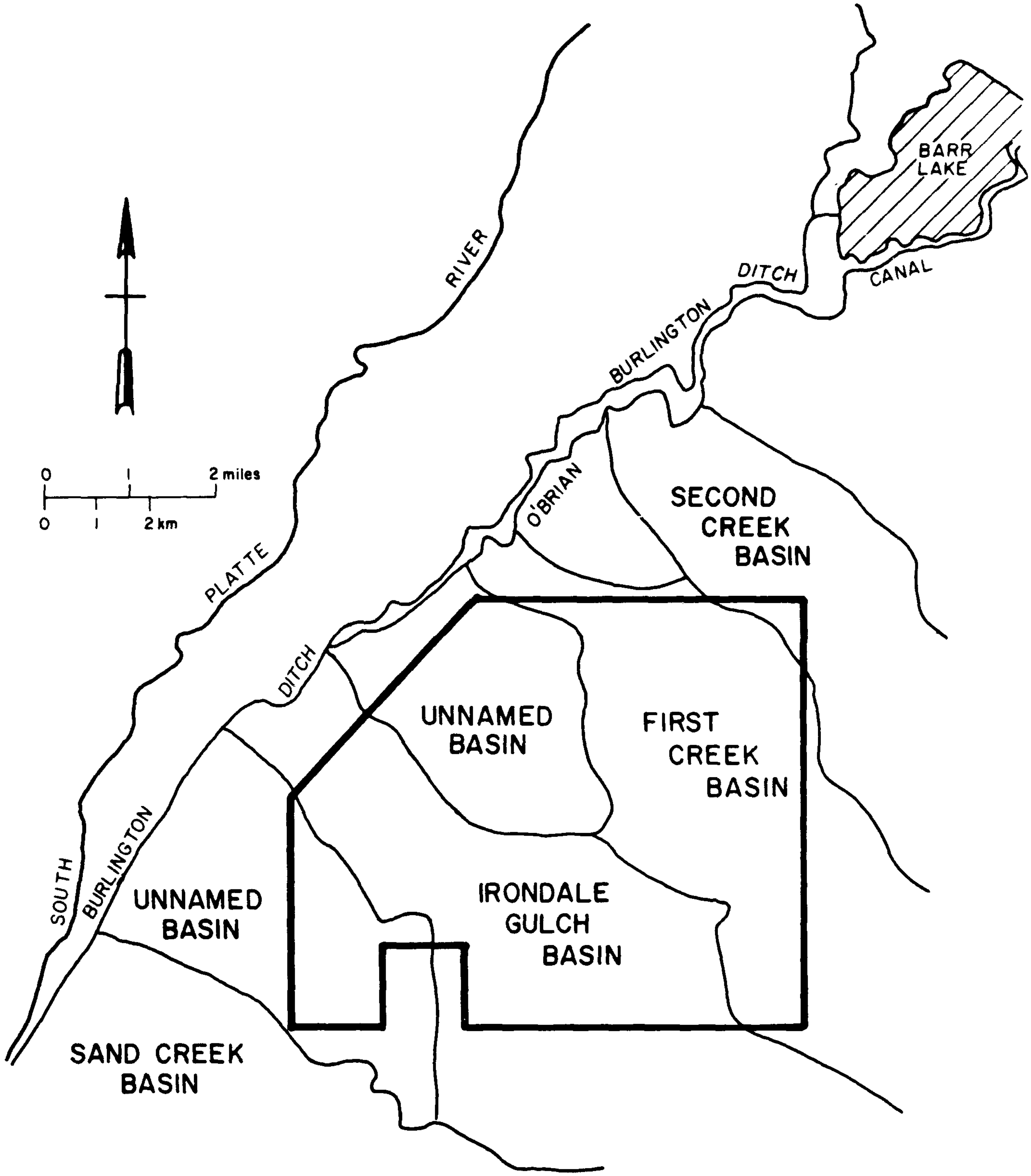

FIGURE 3-1

APPROXIMATE LOCATIONS OF DRAINAGE BASINS ON ROCKY MOUNTAIN ARSENAL

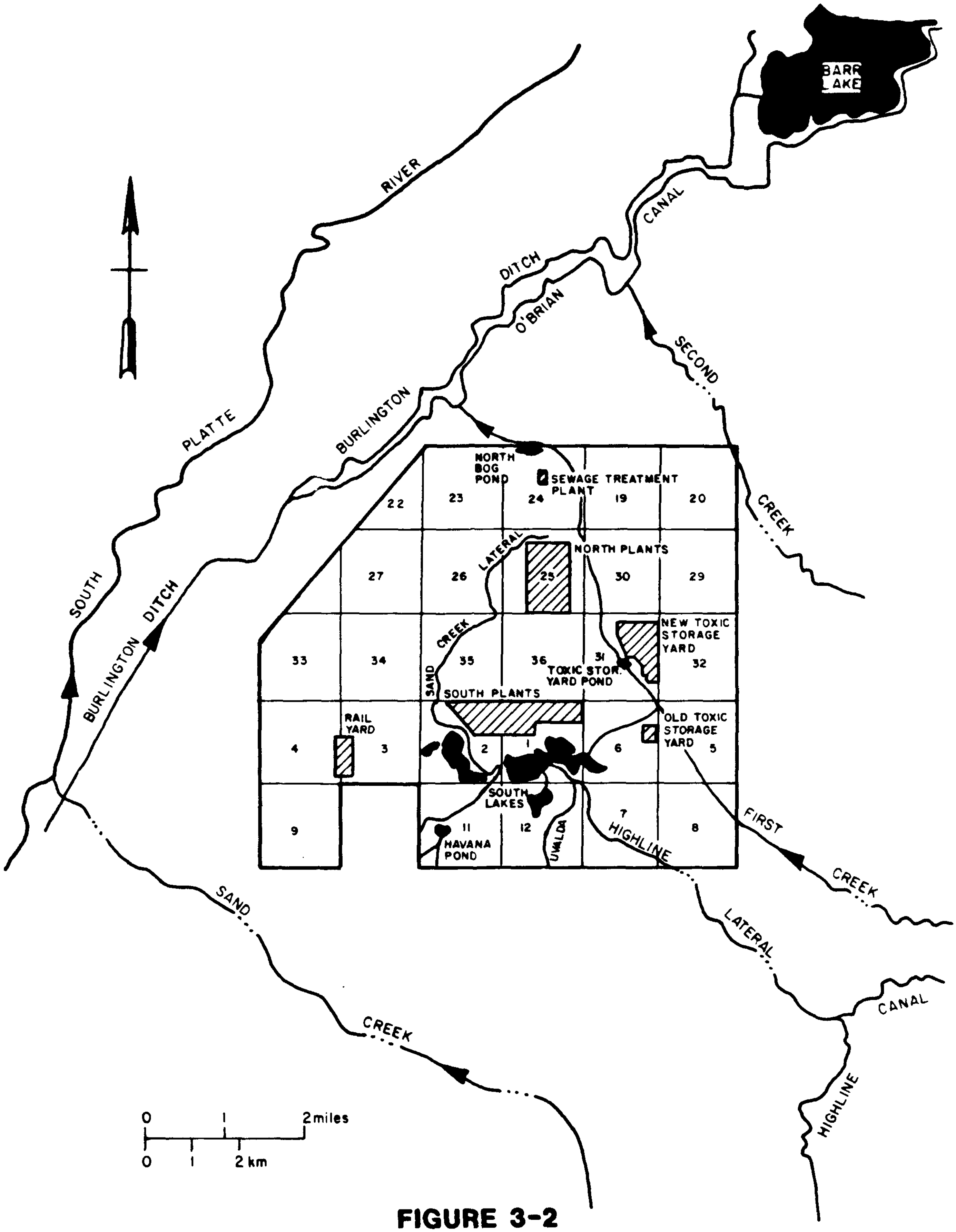

FIGURE 3-2

SURFACE WATERS OF ROCKY MOUNTAIN ARSENAL AND VICINITY

between Sand Creek Lateral and First Creek did not exist in 1956, based on the aerial photographs. First Creek also receives effluent from the sewage treatment plant and overflow water from Upper Derby Lake. A portion of the creek in Section 24 was diverted in 1973 to eliminate a bend in the channel where flooding had occurred (U.S. Army 1983a).

At present, First Creek does not flow directly into the South Platte River, but instead is intercepted by O'Brian Canal and thence fed into Barr Lake north of the site.

3.1.2 Second Creek

The extreme northeastern corner of RMA (about 1 km^2) is part of the Second Creek drainage basin. Total basin size of Second Creek is about half that of First Creek, and it also is intermittent (Fig. 3-1).

Second Creek barely enters the extreme northeastern corner of Section 20 but does not enter the Arsenal (Fig. 3-2). Second Creek is not currently connected to any onsite surface water body, but it previously fed a network of agricultural irrigation canals on what is now RMA land. At present, Second Creek is intercepted by O'Brian Canal.

3.1.3 Irondale Gulch

Most of the southwestern half of the RMA is drained by Irondale Gulch, a broad, shallow drainage lacking a distinct channel (Fig. 3-1). Like First and Second creeks, the lower end of the Irondale Gulch drainage basin is truncated by O'Brian Canal. However, very little if any surface runoff exits the Arsenal via Irondale Gulch, and its contribution to the canal, and ultimately Barr Lake, is therefore minimal. Total basin size of Irondale Gulch is 54 km^2, of which 21 km^2 is located within the RMA. Onsite length of Irondale Gulch is 11.2 km.

3.1.4 Unnamed Basins

About 15 km^2 in the northwestern portion of the Arsenal drains into an unnamed basin between the First Creek and Irondale Gulch systems (Fig. 3-1). This natural depression was chosen by the Army as the location for chemical waste disposal basins A-F. As a result, this area is sometimes referred to as the "Basin A basin."

As with most of Irondale Gulch, precipitation falling in this unnamed basin filters into the soil or collects in shallow depressions. The moisture is then either lost by evaporation or percolates downward and exits the site as groundwater, with no offsite surface flows evident.

The remainder of the Arsenal, about 6 km^2 in the southwestern corner, also lacks distinct channelization and supports no surface flows (Fig. 3-1) Precipitation falling in this area would percolate into the soils and perhaps enter the Commerce City ditch system or otherwise be channeled to Burlington Ditch. This portion of the Arsenal is sometimes described as being part of the Sand Creek system (e.g., see ESE 1986).

3.2 NATURAL PONDS

The only natural body of standing water at RMA, referred to in this report as North Bog Pond, is located just west of First Creek in northern Section 24 and covers about 0.8 ha (Fig. 3-2). The pond is not entirely natural because it is significantly augmented by excess water from the nearby North Boundary Containment/Treatment System. However, the surrounding bog--actually a small marsh fed by a seep--is natural and pre-dates the Arsenal.

3.3 ARTIFICIAL LAKES AND PONDS

Artificial water bodies at RMA include a series of four larger impoundments known collectively as the South Lakes (Lake Mary, Lake Ladora, Lower Derby Lake, and Upper Derby Lake), plus three smaller impoundments (Rod and Gun Club Pond, Toxic Storage Yard Pond, and Havana, or South Gate, Pond) (Figs. 3-2, 3-3).

Three of the South Lakes--Upper and Lower Derby and Ladora--were used for process cooling water in the South Plants area. Water was pumped from the northern (lower) end of Lake Ladora, circulated through various South Plants manufacturing facilities, and then discharged into Upper Derby Lake via an open return-water ditch. The water cooled as it moved through Upper and Lower Derby lakes and finally back to Lake Ladora. In 1963, the return-water ditch was rerouted to bypass Upper Derby Lake and to drain directly into Lower Derby Lake. In 1964, a closed-loop cooling system was installed in which water was run through a cooling tower (Crabtree et al. 1965). The South Lakes were not used to cool the manufacturing processes after that year, but they did continue to serve as a cooling system for the Arsenal's steam plant and to replace water lost from the closed-loop system.

The following subsections briefly describe each of the artificial lakes or ponds on the Arsenal.

3.3.1 Upper Derby Lake

Upper Derby Lake is the easternmost (uppermost) lake in the South Lakes system. It is located in the southern half of Section 1, north of 6th Avenue, and west of "E" Street, and lies within the Irondale Gulch drainage basin (Fig. 3-3).

Upper Derby Lake was formed by constructing a dam immediately east of Lower Derby Lake, probably soon after establishment of the Arsenal (U.S. Army undated a, p. 570). The lake bottom may

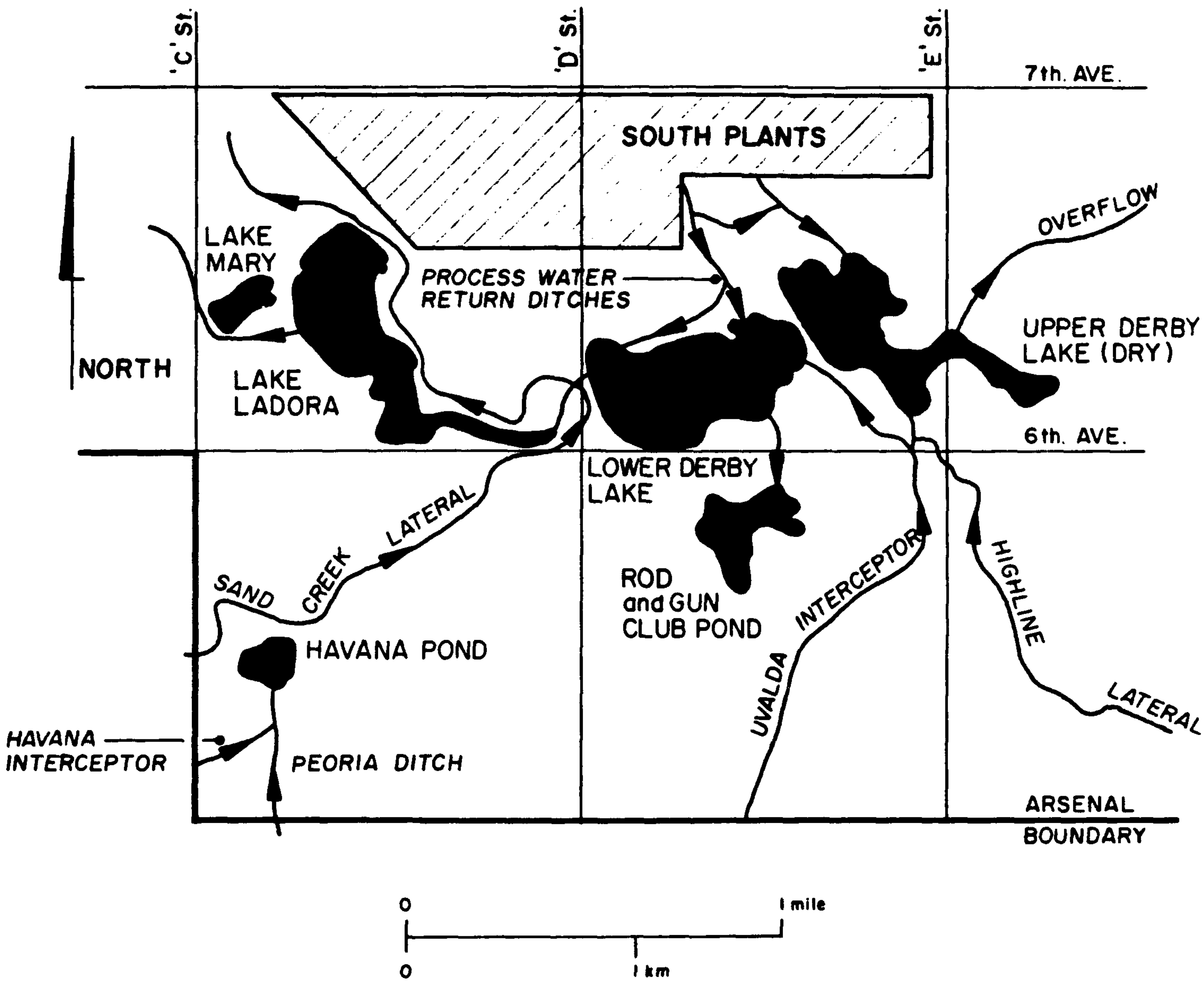

FIGURE 3-3

SOUTH LAKES AND SURROUNDING AREA OF ROCKY MOUNTAIN ARSENAL have been lined with clay to prevent seepage (Gatlin 1960). Before 1963, Upper Derby Lake received process water from the South Plants via the easternmost return-water ditches.

In 1963, use of the eastern return-water ditches ceased, and water from the South Plants was rerouted from Upper Derby Lake to Lower Derby Lake via a 520 m ditch (Williams 1963). Upper Derby Lake was drained so it could be excavated (along with Lower Derby and Ladora lakes) to remove contaminated sediments. This scraping of the sediments in 1964-1965 initially consisted of removing 7-45 cm from the lake bottom (see Section 5.2.3). Areas with suspected high concentrations of contaminants were resampled, and additional sediment was removed in some areas (Crabtree 1964). The sediment was disposed in Sections 11 and 12, just south of the lakes (U.S. Army 1977b). The South Lakes were no longer used for cooling the manufacturing processes, and water levels, especially those in Upper Derby, may have been allowed to fluctuate more than before (RMFC 1978a). In 1981, Upper Derby Lake was revegetated for emergency flood control. In 1982, the Highline Canal and the Uvalda Interceptor, which originally flowed into Upper Derby Lake, were diverted to Lower Derby Lake. Upper Derby Lake has since been used only for flood and overflow storage and often is dry (Ebasco 1986b).

When water is present in Upper Derby Lake, it flows by gravity into Lower Derby Lake via a culvert under a spillway at its western end (U.S. Army 1984). Upper Derby Lake receives surface water primarily from upstream portions of Irondale Gulch and a ditch that drains part of the South Plants. Both the Highline Canal Lateral and the Uvalda Interceptor may be discharged into Upper Derby Lake, but since 1982 these sources have been diverted primarily into Lower Derby Lake.

MKE estimates the lake's surface area at 34.4 ha when full, making it the second largest of the South Lakes in areal extent. The lake has a storage capacity of about 465 acre-feet and an average depth of about 1.7 m.

3.3.2 Lower Derby Lake

Lower Derby Lake is located between Ladora and Upper Derby lakes in the southern half of Section 1, north of 6th Avenue, and east of "D" Street in the Irondale Gulch drainage basin (Fig. 3-3). Lower Derby Lake is the largest reservoir at RMA, with a surface area of about 38 ha, an average depth of 2.6 m, and a volume of 800 acre-feet. Lower Derby Lake probably provides more recharge to the groundwater than it receives, except when its water level is very low.

A smaller version of Lower Derby Lake can be seen in pre-Arsenal (1937) aerial photographs. Possibly it was built by farmers as an irrigation reservoir. In the early 1940s, a dam was built on the eastern side of Lower Derby Lake to increase its storage capacity (U.S. Army undated a, p. 570). The lake may originally have been lined with clay to prevent water seepage (Gatlin 1960). Along with Upper Derby and Ladora, Lower Derby Lake was used as part of the cooling water system for the Arsenal's manufacturing process.

In 1963, drainage from the South Plants area was rerouted from Upper Derby Lake to Lower Derby Lake via a 520 m ditch (Williams 1963). In 1964, a ditch was built on the northwestern end of Lower Derby Lake and was connected to a pipe draining into Lake Ladora (Donnelly 1963). Lower Derby Lake, along with Ladora and Upper Derby, was drained using this diversion to allow the removal of contaminated sediments between 1964 and 1965 (Ebasco 1986b). Initially, 7-30 cm of sediment was removed (see Section 5.2.3). Areas with suspected high concentrations of contaminants were resampled, and additional sediment was removed in some areas (Crabtree 1964). The sediment was disposed in Sections 11 and 12 (U.S. Army 1977b) south of the lakes.

Lower Derby Lake was no longer used to cool the manufacturing processes after 1964, and water levels may have fluctuated more than before, although probably not as much as in Upper Derby Lake (RMFC 1978a). In 1982, the Highline Canal Lateral and the

Uvalda Interceptor were diverted from Upper Derby Lake to Lower Derby Lake. Water from the Highline Canal Lateral was used to fill Lower Derby Lake (Knaus 1982, cited by Ebasco 1986b). As of 1982, Lower Derby was used for water storage for the South Plants operations as well as to maintain water levels in Lake Ladora (Ebasco 1986a). An emergency overflow ditch to carry water from Lower Derby Lake to the Rod and Gun Club Pond was built during a flood in 1973 (Ely et al. 1973).

3.3.3 Lake Ladora

Lake Ladora is located in the center of Section 2, east of "D" Street and between Lake Mary and Lower Derby Lake (Fig. 3.3). Lake Ladora existed as a small reservoir before the Arsenal's establishment and may have been constructed by farmers who owned the land prior to 1942 (Donnelly 1986, cited by Ebasco 1986). Although the date of construction is not documented, a small Lake Ladora is clearly visible on 1937 aerial photographs. A survey in May 1942, prior to the construction of RMA, recommended that the lake be enlarged to increase its storage capacity (Prouty Bros. 1942). This was apparently done sometime shortly thereafter (U.S. Army undated a, p. 570).

Lake Ladora is located in the Irondale Gulch drainage basin. Drainage from the western portion of the South Plants toward the lake is intercepted by the Sand Creek Lateral (COE 1978, cited by Ebasco 1986), which drains to Basin C. However, drainage from the eastern portion of the South Plants indirectly enters Lake Ladora after circulating through the Upper and Lower Derby lakes.

Lake Ladora has been modified or repaired several times since RMA was established. When the lake was enlarged for use as a source of cooling water, the bottom may have been sealed with clay (Gatlin 1960). Later changes included deepening the inlet ditch in 1957 (ESE 1986) and constructing a diversion ditch around Lower Derby Lake to Lake Ladora in 1963 (Donnelly 1963). The lake was drained, and portions of the bottom were scraped to remove contaminated sediment in 1964 (see Section 5.2.3). From 7 to 30 cm of sediment was reportedly removed and disposed south of Lake Ladora in Section 2 (Army Drawing, No. 16-02-01). The western spillway was repaired in 1973 where a flood caused some damage (Unauthored 1973, cited by Ebasco 1986a).

Lake Ladora may act as both a recharge and discharge area for the alluvial aquifer. During periods when the lake is high (usually March through August), it is a recharge area; when the lake is low (September through March), water discharges from the alluvial aquifer into the lake (Ebasco 1986). Prior to 1975, overflows from Lake Ladora could enter Lake Mary, but after that date a ditch was constructed to divert these waters.

MKE hydrologists have estimated the surface area of Lake Ladora to be 24.7 ha, with a storage capacity of about 350 acre-feet. Average water depth is estimated at 1.7 m.

3.3.4 Lake Mary

Lake Mary, the smallest and lowermost of the South Lakes, is directly west of Lake Ladora and east of "C" Street near the western edge of Section 2 (Fig. 3-3). It was constructed for recreational purposes (i.e., fishing and waterfowl hunting) and was never part of the industrial cooling system.

The area where Lake Mary is located was formerly a swampy area created by seepage from Lake Ladora. In 1960, this surface water was ponded by constructing a berm below the Lake Ladora dam (Prentice 1960, cited by Ebasco 1986a). Rod and Gun Club members excavated the area to further complete the construction (Donnelly 1986, cited by Ebasco 1986a). After filling with water, Lake Mary was stocked with fish to provide recreation.

In 1967, tree stumps were removed from Lake Mary and shallow sections were dredged (Mack 1967). The lake was drained in 1974 and enlarged and deepened in 1975 to enhance the quality of the water for fish (Mullan 1975d). During this renovation, a channel was constructed to direct floodwaters from Lake Ladora, which were thought to be contaminated, around the southern edge of Lake Mary. Lake Mary was refilled with water from a deep well, instead of with water from the industrial lakes, to prevent possible recontamination.

A recent Army Corps of Engineers map indicates that a 10 cm steel siphon connects Lake Mary with Lake Ladora (U.S. Army 1984). This siphon was not in evidence during a site visit in June 1986.

Lake Mary is located, along with the other South Lakes, in the Irondale Gulch drainage basin. When it was constructed in 1960, it had a surface area of 2.4 ha and a maximum depth of 2.7 m. It presently covers approximately 3.2 ha and has a maximum depth of 4.6 m. Lake Mary is in contact with the alluvial aquifer and is a point of discharge rather than recharge.

3.3.5 Rod and Gun Club Pond

The Rod and Gun Club Pond is located in a naturally low area in the north-central part of Section 12, south of 6th Street and approximately 365 m south of Lower Derby Lake (Fig. 3-3). Between 1965 and 1971, the low area may have been excavated, because a more clearly defined pond appears on aerial photographs after that period. During a May 1973 flood, an emergency overflow ditch was constructed to carry overflow water from Lower Derby Lake to the Rod and Gun Club Pond (Ebasco 1986b). During 1977, water was pumped from Lower Derby Lake to the Rod and Gun Club Pond to maintain the pond's water level (RMFC 1978a), but it has lost water since that time and presently is less than 1 m deep. The pond receives runoff only from its immediate surroundings and what little additional area is intercepted by the ditch connecting it to Lower Derby Lake, and it has no drainage outlet (Ebasco 1986c). The surface area of the Rod and Gun Club Pond was recently estimated at approximately 7.8 ha when full (Ebasco 1986c), giving a storage volume of about 60-65 acre-feet. However, this estimate apparently includes the surrounding marshy area as well. The actual pond covers only about 2 ha and has a volume of less than 15 acre-feet.

3.3.6 Havana (South Gate) Pond

The Havana, or South Gate, Pond is located in the southwestern corner of Section 12 (Fig. 3-3). Water is supplied primarily by Havana Street Interceptor and Peoria Ditch (see Section 3.4.7), which collect water from residential and commercial/industrial areas south of the RMA. Havana Pond fluctuates markedly in volume, as reflected by the near absence of adjacent hydrophytic vegetation, but it apparently has not completely dried up for at least a few years. When full, this pond covers less than 8 ha and has an average depth of less than 1 m. Based on these estimates, the storage volume of Havana Pond is less than 65 acre-feet.

3.3.7 Toxic Storage Yard Pond

The Toxic Storage Yard Pond is actually a series of three small ponds formed along First Creek in Section 31, just west of the Toxic Storage Yard (Fig. 3-2). The ponds were formed by constructing earthen dams in an area that was previously a marshy depression. In 1977, the Toxic Storage Yard Pond covered 1 ha of surface area and averaged 1 m in depth (Rocky Mountain Fisheries Consultants 1978a). At present, the only surface water remaining is a small pond measuring approximately 9 m by 21 m. The rest of the ponds apparently were drained when high flows in 1984 washed out the earthen dams.

3.4 DITCHES AND CANALS

In addition to the surface water bodies already discussed, various ditches and canals also exist on the Arsenal. Although not aquatic resources, these man-made features are important as conduits of water, sediments, aquatic biota, and, potentially, contaminants from onsite and offsite sources. These ditches and canals are described below.

3.4.1 Highline Canal and Highline Canal Lateral

The Highline Canal runs from its source, the South Platte River above Chatfield Reservoir, for 145 km through metropolitan Denver, crossing many creeks and lake tailwaters before Highline Canal Lateral splits off from it south of the Arsenal. Under normal circumstances, the creeks and tailwaters do not mix with Highline Canal water because the canal crosses them in flumes. Therefore, water in the Highline Canal comes almost totally from the South Platte River, with only small amounts of runoff from areas immediately adjacent to the canal. The Highline Canal does not flow across any part of the Arsenal, but it is the source of water for the Highline Canal Lateral, which does (Fig. 3-2).

The Highline Canal Lateral enters the southeastern corner of the Arsenal in Section 8. It is about 8.4 km long, of which about 2.8 km are on the Arsenal, and has a capacity of about 2.1 cubic meters per second (U.S. Army 1983a). This canal now terminates at Lower Derby Lake, but it originally ran east out of Lower Derby Lake and branched to the north and south. According to aerial photographs, this northern extension has been eliminated.

3.4.2 Sand Creek Lateral

Sand Creek Lateral enters the Arsenal at the center of the western border of Section 11, flows northeastward, skirts the perimeter of Lake Ladora, and continues in a northeasterly direction between Basins B and C where it terminates (Fig. 3-23). Its length is about 14.2 km, of which about 12 km are within RMA boundaries. Pre-Arsenal (1937) aerial photographs show that Sand Creek Lateral originally fed an elaborate system of irrigation canals, that its flow was continuous, and that it emptied into First Creek. By 1948, some of the drainage was altered around the lakes to meet the waste disposal needs of the South Plants area. By 1956, Sand Creek Lateral no longer ran into First Creek but instead terminated at the North Plants in Section 25. Both the 1948 and 1956 photos show an overflow from the lateral into the north end of Basin C, and also into Section 35.

Sand Creek Lateral originally was connected to Sand Creek and was used to carry irrigation water to farms on land now occupied by the Arsenal. Construction of the northern extension of Stapleton International Airport filled in a portion of the lateral and disconnected it from Sand Creek. Since government purchase of the Arsenal site, Sand Creek Lateral has been used for storm drainage (Gauthier et al. 1974) and to transfer toxic wastes to the waste basins (U.S. Army undated d). Today, the disconnected easternmost portion of Sand Creek Lateral drains runoff from the North Plants into First Creek.

3.4.3 O'Brian Canal

O'Brian Canal draws water from the South Platte River via Burlington Ditch (Fig. 3-2). The canal runs for approximately 27 km along a course gradually diverging from the South Platte and branches just south of Barr Lake. One of the branches flows into Barr Lake, and the other flows around the eastern side of the lake as the Denver-Hudson Canal. First Creek, Second Creek, and Third Creek are tributaries to O'Brian Canal. First Creek enters the canal about 0.8 km downstream (north) of the Arsenal.

3.4.4 Uvalda Interceptor

Uvalda Interceptor enters the Arsenal at the center of the southern border of Section 12 and flows north to the Derby Lakes (Fig. 3-3). It is about 2.2 km long onsite, which represents about half of its total length (4.6 km). Uvalda Interceptor was completed in 1967 to channel runoff from the Montbello subdivision, adjacent commercial industrial areas, and surrounding rangeland south of the Arsenal (U.S. Army 1983a). Although it originally flowed into Upper Derby Lake, Uvalda Interceptor has since been diverted to Lower Derby Lake by an earthen dam. Uvalda Interceptor contains flowing water only during heavy rains and floods (Gauthier et al. 1974). Some areas of standing water persist in the interceptor during periods of dry weather, but this is believed to be from groundwater (Resource Consultants 1982a).

3.4.5 Havana Street Interceptor and Peoria Ditch

Havana Street Interceptor enters the Arsenal in the southwestern corner of Section 11 and then joins Peoria Ditch (Fig. 3-3). It has an onsite length of about 0.6 km (total length is 7.2 km). The interceptor drains land with commercial and light industrial development, suburban residential development, and some rangeland (Resource Consultants 1982a). Also included in the Havana Street Interceptor drainage is storm runoff from Stapleton International Airport (ESE 1985).

Peoria Ditch enters the Arsenal along the southern border of Section 11 and empties into Havana or South Gate Pond after merging with Havana Street Interceptor. Its onsite length is 0.7 km. Both Peoria Ditch and Havana Street Interceptor were completed in 1980 (USEPA 1983c).

3.5 FOOD WEBS OF THE ARSENAL SURFACE WATERS

Hazardous compounds released into the environment may be transported physically in the air, soils, groundwater, and surface water. Hazardous compounds may also be distributed among some or all of the species in an ecosystem via the food chain. Understanding food chain dynamics is therefore essential in ascertaining how contaminants are transmitted through the biota. Food chains are divided into trophic levels, which represent the primary path of energy transfer through an ecosystem. In simple terms, energy is transferred from one trophic level to the next when food is ingested. Similarly, contaminants may be transferred from one trophic level to the next. However, whereas energy is dissipated with each transfer between trophic levels (as metabolic heat or digestive inefficiency), contaminants may be concentrated.

Trophic levels are generally classified into four major groupings of organisms: producers (plants), primary consumers (herbivores), secondary consumers (carnivores), and decomposers (bacteria and fungi). Producers, which in aquatic ecosystems include algae and macrophytes, combine energy from solar radiation with nutrients in the soil or sediment to form biomass. Producers serve as the energy (food) source for the primary consumers or herbivores, such as grass carp, tadpoles, and some types of zooplankton and macroinvertebrates. These in turn provide food for the secondary consumers or carnivores, including predacious macroinvertebrates and zooplankton, adult and some larval amphibians, and most fish species. The decomposers then convert the organic debris from other trophic levels into nutrients which are once again available to the producers.

In most ecosystems, simple food chains do not adequately represent the complexity of predator-prey relationships. For example, top predators in the South Lakes (i.e., largemouth bass and northern pike) are at the top of two food chains, one based on phytoplankton and the other on detritus. These more complex trophic interactions within an ecosystem, which frequently include cross-overs between chains, are called a food web. Interactions between food webs are also common. For example, a fish may be eaten by a grebe, which itself is eaten by an eagle or coyote. Thus, energy which originated in an aquatic food web may become part of a terrestrial food web. Similarly, dead terrestrial vertebrates or invertebrates may become part of the organic debris in a lake and thus re-enter the aquatic food web.

The first step in studying the ecology of surface waters at the RMA is to develop a species list for each aquatic habitat. Preliminary lists have been developed by other workers for some of the Arsenal's aquatic habitats (see Table 3-1). These have been documented in the biological inventories conducted for the Army by their fisheries consultants, in various reports prepared by the Fish and Wildlife Service and the Colorado Division of Wildlife, and in biota contaminant studies conducted by the Environmental Branch of the Rocky Mountain Arsenal.

Apparently, no previous studies have been conducted to characterize the aquatic food webs of the Arsenal or surrounding areas. Data have generally been collected for fisheries management purposes, with the exception of a preliminary biological inventory in 1977 (RMFC 1978a) and collection of aquatic plant and animal tissues for contaminant analysis. As a result, only fish species, a few invertebrate species, and prominant aquatic plant species have been identified for Arsenal waters.

The aquatic food webs of aquatic habitats at RMA may be described in general terms, based on the species reportedly present and those observed during initial reconnaissance surveys. General food web characteristics of surface waters at the Arsenal are presented in the following subsections. Phase II field studies will result in a more detailed analysis of food web structure and function.

3.5.1 Lakes and Ponds

The most conspicuous and important surface waters at RMA are the South Lakes. Food webs in these aquatic systems are driven by both detritus and phytoplankton; that is, these two items provide the basic foods for the primary consumers. Detritus, produced mainly by decomposition of the abundant aquatic macrophytes, provides energy for benthic (bottom-dwelling) macroinvertebrates, which in turn are consumed by bottom-feeding fishes. Phytoplankton provides energy for zooplankton, small fishes, and tadpoles, which in turn are prey for predacious macroinvertebrate and fish species. At the top of both the detritus-based and phytoplankton-based food chains are

TABLE 3-1
AQUATIC FLORA AND FAUNA REPORTED FROM SURFACE WATERS OF THE ROCKY MOUNTAIN ARSENAL[1]

SCIENTIFIC NAME[2]	COMMON NAME[2]	WATER BODY[3]
SUBMERSED OR FLOATING AQUATIC PLANTS		
--	Blue-green Algae	NB
Chara kieneri	Muskgrass	LD, RG
Ceratophyllum demersum	Hornwort	LD, LL, LM, RG, NB
Myriophyllum exalbescens	Water-milfoil	LL, LM
Ranunculus trichophyllus	Water Crowfoot	LL, LM
Ranunculus macounii	Macoun's Buttercup	UD
Spirodela polyrhiza	Duckweed	LL, LM
Lemna cf. valdiviana	Duckweed	NB, FC
Najas guadalupensis	Water-nymph	LD
Potamogeton nodosus	Pondweed	SL, RG, TY
Potamogeton pectinatus	Pondweed	LL, LM
Potamogeton pusillus	Pondweed	LD, LL, LM, RG, NB, TY, FC
Potamogeton sp.	Pondweed	LD, LL, LM, RG, NB, TY
Ruppia maritima	Wigeon-weed	RG, NB
Zannichellia palustris	Horned Pondweed	RG, TY, FC
EMERGENT AQUATIC OR SEMI-AQUATIC PLANTS		
Hippochaete laevigata	Scouring-rush	FC
Bidens cernua	Bur-marigold	LM, RG, FC
Bidens frondosa	Beggars-tick	SL, TY, FC
Nasturtium officinale	Water-cress	FC
Rorippa teres	Cress	RG, TY
Rorippa palustris ssp. hispida	Cress	RG
Lycopus americanus	Water Horehound	RG
Persicaria coccinea	Scarlet Smartweed	SL, RG, NB, TY, FC
Salix exigua	Sandbar Willow	SL, RG, TY, FC
Salix inthian	Sandbar Willow	RG
Veronica americana	American Brooklime	TY
Veronica anagallis - aquatica	Water Speedwell	LM, RG, TY, FC
Anemopsis california	Lizard-tail	LL
Limosella aquatica	Mudwort	TY, FC
Alisma plantago-aquatica ssp. brevipes	Water-plantain	LD, LM, TY
Sagittaria cuneata	Arrowhead	UD, TY
Cyperus erythrorhizos	Red-rooted Sedge	UD, LD, LM, RG, TY, FC

Eleocharis acicularis	Needle Spike-rush	LD
Eleocharis macrostachya	Spike-rush	SL, RG, NB, FC
Eleocharis coloradoensis	Spike-rush	LD, LL
Scirpus americanus	Tule	UD, LD
Scirpus paludosus	Alkali Bulrush	LD
Scirpus lacustris ssp. validus	Great Bulrush	UD, LD
Scirpus supinus ssp. saximontanus	Bulrush	LD
Juncus bufonius	Toad Rush	LM
Juncus articus ssp. ater	Arctic Rush	LD, NB, TY, FC
Juncus torreyi	Rush	SL, RG, FC
Juncus cf. marginatus	Rush	LD
Juncus interior	Rush	UD, LD
Typha angustifolia	Narrowleaf Cattail	SL, RG, NB, TY, FC
Typha latifolia	Broadleaf Cattail	UD, LL, LM, RG, NB, TY, FC
INVERTEBRATES		
--	Unidentified Zooplankton	UD, LD, LL
Erpobdella punctata	Leech	Unspecified
Helobdella fusca	Leech	Unspecified
Helobdella stagnalis	Leech	Unspecified
Haemopis marmorata	Horse Leech	Unspecified
Lumbriculus inconstans	Aquatic Earthworm	Unspecified
Limnodrilus claparedianus	Aquatic Earthworm	Unspecified
Limnodrilus hoffmeisteri	Aquatic Earthworm	Unspecified
Tubifex tubifex	Aquatic Earthworm	Unspecified
Hyallela azteca	Sideswimmer	Unspecified
Gammarus spp.	Scuds	LM
Daphnia spp.	Water-fleas	LM
Ceriodaphnia spp.	Water-fleas	LM
Orconectes causeyi	Crayfish	LD, LL, LM, FC
Chironomus spp.	Midges	LD, LL, LM
Physa spp.	Aquatic Snails	UD, LD, LL
FISH		
Salmo clarki	Cutthroat Trout	LM
Salmo gairdneri	Rainbow Trout	LM
Cyprinus carpio	Common Carp	UD, LD
Pimephales promelas	Fathead Minnow	FC
Notemigonus crysoleucus	Golden Shiner	LM, LL
Notropis lutrensis	Red Shiner	LM, FC
Fundulus zebrinus	Plains Killifish	FC
Catostomus commersoni	White Sucker	UD, LD, LL
Ictalurus melas	Black Bullhead	SL, RG, TY
Ictalurus punctatus	Channel Catfish	LD, LL, LM
Lepomis macrochirus	Bluegill	SL, RG, TY
Lepomis cyanellus	Green Sunfish	SL, RG, FC

Lepomis microlophus	Redear Sunfish	LM
Pomoxis nigromaculatus	Black Crappie	LM
Micropterus salmoides	Largemouth Bass	SL, RG, TY
Perca flavescens	Yellow Perch	LD, LL
Esox lucius	Northern Pike	LD, LL, RG, TY

AMPHIBIANS

Scaphiopus bombifrons	Plains Spadefoot	Not specified
*Bufo woodhousei**	Common Toad	Not reported
*Pseudacris triseriata**	Northern Chorus Frog	Not reported
*Rana pipiens**	Northern Leopard Frog	Not reported
Rana catesbiana	Bullfrog	Not specified
*Ambystoma tigrinum***	Tiger Salamander	LL, LM, NB

* Not reported, but observed during field reconnaissance surveys.

** Larvae erroneously reported as *Necturus maculosus*, mudpuppy, a species that does not occur in Colorado.

[1]Includes documented introductions as well as captures and does not necessarily reflect present occurrences. Also not a complete listing, except perhaps for fish.

[2]Reported names updated when necessary; taxonomic sources were Weber (1976) for plants, Pennack (1978) for invertebrates, Lee et al. (1980) for fish, and Hammerson (1982) for amphibians.

[3]Based on Bartschi (1968), RMFC (1978a), Rosenlund (1982, 1985), and Rosenlund et al. (1986). UD = Upper Derby Lake, LD = Lower Derby Lake, LL = Lake Ladora, LM = Lake Mary, SL = South Lakes (all of the above), RG = Rod and Gun Club Pond, NB = North Bog Pond, TY = Toxic Storage Yard Pond, FC = First Creek.

piscivorous fishes, especially largemouth bass and northern pike. The South Lakes have similar ichthyofaunas, with the dominant species reportedly being northern pike, largemouth bass, bluegill, and black bullhead, all of which are secondary consumers (Table 3-1). Lake Mary previously contained rainbow trout (also a secondary consumer), but the trout have probably been displaced by largemouth bass (Rosenlund 1982).

Toxic Storage Yard Pond has generally supported the same dominant fish species as the South Lakes. However, too little is presently known about other species present, or the dynamics of the species reported, to comment on the food web of this pond. North Bog Pond apparently contains both detritus and phytoplankton as bases for a food web, but the only vertebrate species reported in the literature as being present is the tiger salamander. The limited amount of information currently available on the species composition of Road and Gun Club Pond and Havana Pond precludes a meaningful characterization at this time.

3.5.2 Creeks, Canals, and Ditches

Food webs in First Creek probably are driven solely by detritus, because plankton populations are rarely associated with intermittent streams. Three species of fish--plains killifish, fathead minnows, and green sunfish--have been found in First Creek, as have crayfish (RMFC 1978a). The detritus base of the food chain in these streams is decomposed resident plant material (autochthonous detritus) and material brought in with runoff (allochthonous detritus). The detritus is fed upon by crayfish, snails, and other bottom-dwelling organisms, which are the prey base for the resident fishes.

It is doubtful that true food webs exist in the various canals and ditches on the Arsenal because of their temporary flows. Rather, any food present probably comes from outside sources.

A system of man-made ditches, totaling approximately 2,400 m in length, was constructed to return process water and surface runoff from the South Plants area to the lakes. Some of these ditches, notably the return water ditches from the South Plants area to Lower Derby Lake, have reportedly provided habitat for fingerling bass, green sunfish, bullheads, and carp (RMFC 1978a). Riparian vegetation does exist along their margins. They are mentioned here primarily because they are a possible source of contamination to the South Lakes. Toluene, aldrin, dieldrin, isodrin, arsenic, chromium, copper, lead, mercury, and zinc have all been detected in sediment samples from the ditches (Ebasco 1986e).

4.0 HISTORY OF FISHERIES MANAGEMENT

This chapter summarizes what is known about the history of fisheries management at RMA. In general, these activities have been carried out in an effort to establish, re-establish, or maintain a recreational resource, particularly at the South Lakes. Another benefit of fisheries management is that it also often results in aquatic ecosystems of greater value for wildlife by providing a better forage base for fish-eating waterfowl, wading birds, and raptors.

Some of the most important and widely used tools of fisheries management are fish introductions, habitat manipulation, and population control. These types of activities usually are the responsibility of state and federal fish and wildlife agencies, although introductions frequently are made by fishermen who move fish between bodies of water or inadvertently introduce species by releasing bait "minnows". Fish introductions, whether by management agencies or fishermen, or through natural invasions via canals, together have resulted in the present distribution of fish and some invertebrate species at RMA. Table 4-1 presents documented fish stocking activities on the Arsenal.

4.1 SOUTH LAKES

Certainly the most important fisheries on the Arsenal--and consequently those that have received the great majority of active management--are the impoundments known collectively as the South Lakes. It is not clear when fish were first introduced into the two lakes that pre-dated the Arsenal (i.e., Ladora and Lower Derby), but Finley (1959) reported that angling by convalescent patients from Fitzsimmons Army Hospital, located a few kilometers to the south, occurred very early in the RMA's history.

The amount of fishing pressure received, species being caught, and whether the fish were planted or had invaded naturally are not know. It is known, however, that the fisheries had declined

TABLE 4-1
FISH STOCKING HISTORY FOR
ROCKY MOUNTAIN ARSENAL (1961-1982)

Water Body	Year	NUMBER AND SIZE (CM) OF EACH SPECIES[1] Rainbow Trout	Northern Pike	Channel Catfish	Bass	Sunfish	Bluegill	Black Crappie
Mary	1961	500	--	300	--	900(5)	--	--
	1964	2,000	--	--	--	--	--	--
	1965	4,000	--	--	--	--	--	--
	1967	7,000	--	--	--	--	--	--
	1968	8,176(17)	--	--	--	--	--	--
	1969	8,000(20)	--	--	--	--	--	--
	1970	7,000(17)	--	1,500(17)	--	--	--	--
	1971	8,547(20)	--	--	--	--	--	--
	1972	8,000(20)	--	--	--	--	--	--
	1973	7,400(20)	--	1,500(20)	--	--	--	--
	1974	5,900(20)	--	--	--	--	--	--
	1975	3,500(15)	--	1,500(5)	--	--	--	--
	1976	9,000(22)	--	2,000(5)	--	--	--	--
	1977	476(20)	--	--	--	--	--	--
	1978	896	--	--	--	--	--	--
	1979	250	--	--	--	--	--	--
	1982	--	--	--	--	--	--	3,000(2)
Lower Derby	1976	--	3,000(5)	--	--	--	--	--
	1978	--	200(12)	--	--	--	--	--
	1979	--	4,250(2)	--	--	--	--	--
Ladora	1967	--	--	25,000(2)	--	--	Unknown[2]	--
	1968	--	500,000(2)	5,000(6)	--	--	--	--
	1969	--	--	--	16,000(5)	--	4,000(5)	--
	1970	--	39(7)	--	--	--	--	--
	1976	--	3,000(7)	--	--	--	--	--
	1978	--	300(12)	--	--	--	--	--
	1979	--	4,250(2)	--	--	--	--	--
Upper Derby	1979	--	1,000(2)	--	--	--	--	--
Rod & Gun Club	1976	--	1,600(5)	--	--	--	--	--
	1979	--	500(2)	--	--	--	--	--
Toxic Storage Yard	1976	--	600(5)	--	--	--	--	--
North Bog	1976	--	600(5)	--	--	--	--	--

Data sources: Bartschi (1968,1969); Mack (1962); Mullan (1971a, 1974d, 1975d); Rosenlund (1978b,1978d).

[1]Some conflicting data was reported in the documents. Numbers reported here were from the most contemporaneous source.

[2]Undocumented number of bluegill transferred from Lake Mary.

08/26/87

drastically by the late 1940s, apparently because caustics had been put into the lakes by the Army (see Section 5.2.1). Fish were reportedly absent from the South Lakes in the summer of 1951 (Hyman 1953a). Discussions about restocking the lakes were held between the Army and Hyman on several occasions in 1951, but whether fish were re-introduced at that time is not documented.

No additional information on the South Lakes fisheries is evident prior to 1960, when Lake Mary was constructed and the U.S. Fish and Wildlife Service became involved in actively managing the aquatic resources of the Arsenal (Rosenlund 1981). In 1964 and 1965, fisheries of the South Lakes (except Lake Mary) were eliminated when the lakes were drained and sediments were removed to effect a partial cleanup (see Section 5.2.3). These lakes were subsequently restocked by the Fish and Wildlife Service (Mullan 1971).

Management of aquatic resources at RMA since then has varied considerably among the water bodies. The following discussions summarize the management of the South Lakes, which has been aimed at monitoring and improving the recreational resources as well as obtaining materials for contaminant analyses. Subsequent subsections similarly address other aquatic resources at RMA.

4.1.1 Upper and Lower Derby Lakes

The Derby Lakes were apparently not supporting a fish population in 1968, although channel catfish fingerlings were planted on an experimental basis that year (Bartschi 1968). The next documented management effort at the Derby Lakes occurred in 1975, when crayfish were introduced as a forage base for largemouth bass. It is possible that efforts to restock the Derby Lakes were made in the interim (Mullan 1975d), or at least that they were restocked with species other than channel catfish in 1968. This could not be established for certain (see Rosenlund 1981), but a large number of dead bass, bluegill, and "catfish" were observed along the shore of Lower Derby Lake in May 1973 (U.S. Army 1973a). If the catfish were black bullheads, they could have invaded via the Highline Canal Lateral or been released by fishermen. The bass and bluegill could have entered this way also, but the prevalence of those two species strongly suggests a concerted stocking program.

In September 1975, the Fish and Wildlife Service surveyed the Derby Lakes with a gill net set overnight in each lake (Mullan 1975d). This trapping effort yielded a large number of black bullheads in both lakes, and the Fish and Wildlife Service's 1975 Annual Fisheries Report stated that the "reservoirs are on the verge of being overrun with black bullheads". It was felt that this overcrowding would soon reduce the average size of the fish. Three thousand 5-7.5 cm northern pike were introduced into the Derby Lakes (probably only in Lower Derby) in May of 1976 (USFWS Undated b). There are indications (e.g., Rosenlund 1981) that pike had also been planted in 1975, but this could not be verified. The pike, a top predator and game fish, would have had an excellent forage base due to the large number of bullheads present at the time.

A preliminary biological inventory performed by Rocky Mountain Fisheries Consultants in 1978 (RMFC 1977) indicated that Upper Derby Lake had little potential for supporting a viable recreational fishery because water level fluctuations precluded successful reproduction. The consultants also noted that a complete fish kill occurred in September 1977, reportedly due to low oxygen levels, high turbidity, a large phytoplankton bloom, and stagnation of the lake. It was not indicated whether these observations were qualitative or supported by actual measurements. Fish observed in potholes during this fish kill were black bullheads, carp, western white suckers, largemouth bass, bluegill, and green sunfish.

Sampling of Lower Derby Lake in 1977 (RMFC 1978a) indicated that it was the most productive and well balanced fishery on the Arsenal and that fish were generally larger than in the other lakes. Black bullhead were the most abundant species, but they apparently were not stunted by overpopulation. Spawning success of largemouth bass was found to be high, while bluegill and green sunfish reproduction was relatively low. Yellow perch were present in low numbers, and northern pike--probably from the 1976 stocking--were also captured. The pike were 25-30 cm in length, which represents considerable growth during their two summers in Lower Derby Lake. Moderate populations of carp and western white sucker were also noted, but survival of native forage minnows was found to be low.

Fish populations in the return water ditch from the South Plants were sampled by electroshocking during 1977 (RMFC 1978a). In this sampling, the population and survival rate of bass fingerlings were larger than the fingerling populations of bullhead, carp, and green sunfish, but all fish species were found to have at least moderate reproduction and survival. This indicates that the ditch provided suitable habitat for the fingerlings to feed and to avoid the heavy predation pressure in the lakes.

In a further attempt at establishing a good reproducing population of northern pike, 200 fish 12.5 cm in length were stocked in Lower Derby in 1978 (Rosenlund 1978d). The populations were to be surveyed later to monitor spawning success. Pike may also have been stocked in 1977 (Rosenlund 1981), but this could not be verified.

Population surveys conducted in 1981 indicated that the northern pike were having limited spawning success (Rosenlund 1981). Pike captured in 1981 were between 43 and 69 cm in length and were thought to be feeding on white suckers and bluegill. Sampling in 1982 indicated that at least six year classes were represented, and the population had increased by natural reproduction. The pike were reported to be feeding primarily on bullheads in 1982 (Rosenlund 1982).

Sampling in Lower Derby Lake between 1978 and 1981 revealed that largemouth bass were low in number and ranged from 15 to 38 cm in length (Rosenlund 1981). They appeared to be feeding on bluegills and were growing an average of 7.5 cm per year. By 1982, the bass population had stabilized, and the bass reportedly were utilizing crayfish as their forage base (Rosenlund 1982). This shift in diet was assumed to have resulted from a decline in the number of bluegill, which were thought to have disappeared for Lower Derby Lake by 1982.

Bullheads still dominated the Derby Lakes in 1981 and had increased in mean size to about 25 cm, compared to about 20 cm in 1979 (Rosenlund 1981). However, by 1982 bullhead numbers had dropped, and they were no longer reproducing (Rosenlund 1982). Low water levels in 1982 were thought to have contributed to the decline, but it was believed that the large population of predator fish species (bass and pike) was the major factor (Rosenlund 1982). Decreases in yellow perch and western white sucker populations during this period were also attributed to the predation by bass and pike.

Fish and Wildlife Service biologists sampled Lower Derby Lake in 1984 and found northern pike and common carp to be abundant (Rosenlund et al. 1986). Largemouth bass, bluegills, and black bullheads also were captured during the sampling, the latter two species in low numbers. A few crayfish and two amphibians (one toad, one bullfrog) also were collected during this sampling.

4.1.2 Lake Ladora

The earliest documented fisheries management activity at Lake Ladora was in 1967, when the Fish and Wildlife Service planted 25,000 channel catfish fry and released an unknown number of stunted bluegill seined from Lake Mary (Bartschi 1968). The next year, 500,000 northern pike fry were planted into Lake Ladora (Mullan 1975d). These stockings apparently showed little sign of initial success. In August 1968, three experimental gill nets of differing mesh size were set for 48 hours each.

Only one 10-cm green sunfish was captured. Channel catfish fingerlings were again planted, on an experimental basis, in October 1968 (Bartschi 1968). That same month, Fish and Wildlife Service biologists set two 46-m gill nets of undocumented mesh size. No fish were captured, but approximately 25 tiger salamanders (presumably larvae) were found in each net (Bartschi 1968). Fish and Wildlife Service personnel observed dipterans, cladocerans, snails, frogs, and aquatic plants in Lake Ladora during the October 1968 visit.

In June 1969, the Fish and Wildlife Service stocked Lake Ladora with 4,000 bluegill and 16,000 largemouth bass (Bartschi 1969). Both species averaged 5 cm in length (Mullan 1975d). Between 50 and 100 largemouth bass, ranging from 10 to 20 cm in length, were later observed near the outlet of the lake, and large schools of similar-sized largemouth bass were seen near the inlet (Bartschi 1969). Ten to twelve bluegill were observed over spawning beds, and large schools of "minnows" were observed along the shoreline. The "minnows" probably were either fathead minnows or red shiners.

The only stocking in Lake Ladora in 1970 was the introduction of thirty-nine 10-cm northern pike in May by the Fish and Wildlife Service (Mullan 1975d). Observations and seining indicated that fathead minnows were abundant at that time and that survival and growth of the bluegills and bass stocked in 1969 was good (Mullan 1971a). Three gill nets set overnight in May 1970 yielded 43 bluegill ranging in size from 10 to 18 cm, 80 largemouth bass from 15 to 28 cm, one green sunfish, and one western white sucker. However, in 1970 high levels of dieldrin were detected in largemouth bass and bluegill tissue (3.94 and 3.05 ppm, respectively), and because there was no allowable tolerance for dieldrin in food. Lake Ladora was closed to fishing at that time (Mullan 1975d).

In 1972, the Fish and Wildlife Service again set three gill nets overnight (Mullan 1975d). Fewer bass were captured than in 1970

(48 vs. 80), but they were larger in size, ranging from 25 to 33 cm. The 1972 bluegill catch consisted of more than three times as many fish as in 1970 (131 vs. 43), and lengths ranged from 7.5 to 25 cm. Twenty-three green sunfish were caught, ranging from 10 to 23 cm. A small number of black bullheads were also captured.

The next record of management activities in Lake Ladora was in 1974, when the Army opened the lake to catch-and-release fishing (Mullan 1974b). Largemouth bass weighing up to 2.7 kilograms (kg) and northern pike up to 10.9 kg were reported by anglers. A few 46 cm northern pike were observed near the surface of the water by a Fish and Wildlife Service biologist. The biologist also saw a dead northern pike, weighing an estimated 11 kg, on the bank.

Two gill net samples in September 1975 revealed an increase in black bullheads, which numbered 244 (versus only 3 caught in 1972) and ranged between 15 and 33 cm in length (Mullan 1975d). Their size distribution appeared to be normal, according to the biologists conducting the study. Yellow perch (32 in number) were captured for the first time in 1975; the researchers thought that they possibly had entered the lakes through the Highline Canal Lateral. Scale analysis of the perch indicated that they were all at least one year old, and it was feared that they might eventually overpopulate the waters. The number of bluegill captured in 1975 was almost identical to 1972 (134 vs. 131), but their growth appeared to be declining. Largemouth bass decreased in number compared to 1972 (9 vs. 48), but their growth was reasonably good. Only one green sunfish was captured in 1975. As previously mentioned, the Fish and Wildlife Service introduced crayfish into Arsenal waters in 1975 in hopes that they would establish breeding populations and contribute to the forage base; Lake Ladora received 110 adult crayfish in that year. No northern pike were netted in the 1975 survey (Mullan 1975c).

The preliminary biological inventory performed by Rocky Mountain Fisheries Consultants in 1977 showed that bluegill had become the dominant species in Lake Ladora and that overpopulation had stunted growth (RMFC 1978a). An overabundance of aquatic vegetation was thought to be contributing to the overabundance of the bluegills by providing cover from predatory species. Largemouth bass and bullhead populations were found to be of reasonable size, although it was thought that the bass population could be increased by removing some of the aquatic vegetation. The pike population was moderate, but there was no evidence of pike reproduction. The populations of green sunfish and yellow perch were low, which was attributed mainly to competition with the bluegill for food and habitat. The western white sucker population was also low in 1978.

Gill-netting by the Fish and Wildlife Service in 1978 captured one hundred six 23-25 cm bullheads, three 35-74 cm northern pike, two 20 cm yellow perch, one 15 cm bluegill, and one 37 cm largemouth bass (Rosenlund 1978d). Three hundred 12 cm northern pike were also planted that year in the continuing effort to establish a good breeding population.

Black bullhead abundance remained high in Lake Ladora from 1979 through 1981, with an average of about 80 captured per net. During this period, their mean size increased from approximately 20 cm to 25 cm (Rosenlund 1981). Bullhead captures fell to only about 20 per net in 1982, which Rosenlund (1982) attributed to the increasing northern pike population. Largemouth bass numbers remained low in 1981, their size ranged from 15 to 37 cm, and they were growing an average of 7.5 cm per year (the same as in Lower Derby Lake). The bass were found to be feeding primarily on bluegill in both 1981 and 1982 (Rosenlund 1981, 1982). The pike caught in Lake Ladora were the largest in Arsenal waters. In 1982 they ranged from 40 cm to 94 cm in length, representing six age classes. The pike were utilizing white suckers and bluegills as forage (Rosenlund 1982). As in Lower Derby Lake, both yellow perch and white sucker had decreased by 1982, which Fish and Wildlife Service attributed to predation by pike. A previously uncaptured species, the golden shiner, was caught in Lake Ladora in 1982 (Rosenlund 1982).

Lake Ladora was again sampled with gill nets in 1984 (Rosenlund et al. 1986). Northern pike, largemouth bass, and bluegill were abundant, and bullheads were common. No amphibians were caught but they were reported as being present in low numbers.

4.1.3 Lake Mary

Lake Mary was constructed in 1960 for recreational purposes (Azevedo 1960), and it was filled with seepage water from Lake Ladora, located immediately upstream. Carp were seen in the reservoir in 1960. A fisheries management plan was set up by the Fish and Wildlife Service as soon as the lake was constructed. The lake was initially stocked in 1961 by the Colorado Division of Wildlife with channel catfish, redear sunfish, largemouth bass, and rainbow trout (Mullan 1975d). Annual restockings of catchable-size rainbow trout were made to maintain a put-and-take fishery. Bluegill (origin unknown) were first noted in 1962. From its inception, Lake Mary was managed as a "put and take" fishery; that is, fish were stocked to be caught and taken home by anglers.

Catch and effort data collected by Arsenal personnel using forms provided to anglers showed that rainbow trout (reportedly weighing up to 2.2 kg) comprised the largest percentage of the catch during the early 1960s. Large redear sunfish (to 0.5 kg), and and channel catfish (to 2.0 kg) also were reported by the anglers, but not in great numbers (Mullan 1975d). Fishing pressure rose during the following years (1964-1969) and, in response, Fish and Wildlife Service personnel doubled the number of trout stocked. Harvest rates for warmwater species also increased. Redear sunfish disappeared from the catch and were replaced by bluegill (Mullan 1975d). The catch per effort for trout and largemouth bass declined sharply during the late 1960s, and Lake Mary became overpopulated with small bluegill.

In 1967, Arsenal personnel attempted to alleviate the problem by seining numerous small bluegill, but this did not seem to be successful (Mullan 1975d).

Low concentrations of dissolved oxygen and excessive algal and macrophytic growth prompted Arsenal personnel to apply a herbicide and an algacide to the lake and to artificially aerate it by bubbling air through a perforated hose placed on the bottom (Bartschi 1969). These efforts apparently were successful.

Because of continuing problems with bluegill overpopulation, Lake Mary was drawn down in 1970 and treated with Rotenone, a chemical which impedes oxygen transfer across the gill lamellae and is therefore lethal to fish. This application completely eliminated the fishery. Dead fish observed included numerous small bluegill, a few largemouth bass, approximately 200 rainbow trout, and a large number of black bullheads, which had not been stocked but possibly could have invaded the system through the spillway from Lake Ladora (Mullan 1971a).

Later in 1970, Lake Mary was refilled with water from Lake Ladora, channel catfish were restocked, and seasonal stockings of rainbow trout were resumed. The fishery was satisfactory for the next two years. However, by 1973 it had again declined due to a large increase in the number of green sunfish, which apparently entered the lake in 1970 when it was refilled. There was also a problem with high densities of aquatic weeds (Mullan 1975d).

Once again, plans were made to renovate the fishery by poisoning and restocking. Poisoning in 1974 revealed an overpopulation of green sunfish, a few largemouth bass that may have escaped from Lake Ladora during a flood or been planted by fishermen, and about 200 channel catfish (Mullan 1975b). In 1975, Lake Mary was deepened an unspecified amount and enlarged from 2.4 to 3.2 ha (Mullan 1975d). It was then filled with groundwater seepage instead of water from Lake Ladora to avoid introducing undesirable species. At the same time, a new canal was dug around the eastern and southern sides of Lake Mary to prevent Lake Ladora overflows from entering. The lake was stocked with channel catfish, and management efforts for the put-and-take trout fishery were resumed (Mullan 1975d). Two hundred immature and 49 adult crayfish were introduced to Lake Mary by the Fish and Wildlife Service in 1975 to augment the forage base and to help control the weed problem (Mullan 1975d). Trout were stocked again in 1976 and 1977 (Robinson 1977).

In May 1977 analyses of tissue from trout that had overwintered one season showed dieldrin concentrations as high as 2.0 ppm (Robinson 1977). Due to this accumulation of contaminants, it was decided by Arsenal personnel and Fish and Wildlife Service staff that fish from Lake Mary should no longer be kept by anglers and that future stocking should be for experimental purposes and fish population control only (Rosenlund 1978d). Accordingly, the number of trout stocked from 1977 to 1979 dropped considerably.

During these years, various strains of rainbow trout were marked and stocked to evaluate differences in rates of growth, survival, and tissue uptake of pesticides. Trout stocked in 1977 were Arlee, Dunn, and Carbondale rainbow trout strains, Snake River cutthroat trout, and "cutbows" (cutthroat-rainbow hybrids) (Rosenlund 1978c). In 1978, White Sulphur and Saratoga rainbow trout strains were stocked (Rosenlund 1978d). Analysis of tissue from six rainbow trout recaptured after 6 months showed that half had dieldrin concentrations in edible portions (fillets) above the Federal Drug Administration action level of 0.30 ppm. In comparison, dieldrin levels were below the detection limit for trout taken directly from the stocking truck prior to release to determine background levels. Stomach analyses of eight trout captured from Lake Mary during this sampling revealed a diet of aquatic snails and algae.

The preliminary biological inventory conducted in 1978 by Rocky Mountain Fisheries Consultants showed that Lake Mary had a critical aquatic weed problem, precluding the development of a healthy, productive fishery (RMFC 1978a). Most rainbow trout sampled were in only poor condition based on low growth rates, although they were generally free of disease. The forage base appeared to be adequate and was composed primarily of red shiners. Bass and bullheads were present, but they apparently had been released by fishermen or invaded naturally via overflow from Lake Ladora and were not an established population. The channel catfish stocked in 1975 had been depleted, either by fishing pressure or natural mortality, and tiger salamander larvae were present in small numbers.

From 1978 through 1981, largemouth bass replaced trout as the dominant game fish (Rosenlund 1981). Bass sampled during this period ranged from 15 cm to 38 cm in length. By 1980, however, the increase in the bass population was offset by a decrease in condition and length, with few bigger than about 20 cm (Rosenlund 1981). This was attributed to a poor forage base, consisting almost entirely of aquatic invertebrates. The Fish and Wildlife Service suggested introducing black crappie into Lake Mary to provide a forage base for the bass and improve angling opportunities. Also, because adult black crappie are piscivorous, they would help prevent the bass from becoming overpopulated. This recommendation was followed, and 3,000 black crappie fry were planted in Lake Mary in June 1982 (Rosenlund 1982, Thorne 1980b).

Lake Mary was gill-netted by the Fish and Wildlife Service again in 1984 (Rosenlund et al. 1986). The fishery "was dominated by a declining population of stunted old bass." A few large bluegill, black crappie, and channel catfish were also collected. Amphibians were present in low numbers, but none was captured.

4.2 OTHER RMA WATER BODIES

4.2.1 First Creek

The only documented sampling of First Creek was electrofishing in 1977 as part of the Arsenal-wide biological inventory conducted by Rocky Mountain Fisheries Consultants (RMFC 1978a). The plains killifish, a native topminnow, was the most abundant fish in the stream, although its population was rather low. Green sunfish and fathead minnows were both found at low population densities. Crayfish were also collected; this population was estimated to be the largest crayfish population on the Arsenal. No fish were caught below the sewage treatment plant effluent pipe in Section 24, near the northern boundary of RMA.

4.2.2 Toxic Storage Yard Pond

Northern pike approximately 5 cm long were stocked in Toxic Yard Storage Pond in 1976 (USFWS undated b). Sampling of the Toxic Storage Yard Pond in 1977 (RMFC 1978w) with a 30 m gill net showed black bullhead to be the most numerous species, with largemouth bass second in abundance. Northern pike and bluegill were also collected. Sizes of pike captured were not reported. Since no other fish were stocked for management purposes, the species besides pike presumably invaded naturally or were introduced by fishermen. No further management actions for the Toxic Storage Yard Pond were found in the literature reviewed.

4.2.3 Rod and Gun Club Pond

Fish and Wildlife Service personnel stocked the Rod and Gun Club pond with 1,600 pike (5 cm in size) in 1976 (USFWS undated b). No other information on stocking could be found. In 1977, the Rod and Gun Club Pond contained only a small amount of water when it was sampled by Rocky Mountain Fisheries Consultants (RMFC 1978a). It consisted of three small, shallow pools (mean depth = 0.75 m) with a combined surface area of about 1.6 ha.

Fish netted during the study included 154 black bullheads, 51 bluegills, 10 largemouth bass, 9 green sunfish, and 1 northern pike. Sizes for all fish species captured were small, ranging from 10 to 18 cm. The small size of the fish was attributed by the study team to an overpopulation by black bullhead and bluegill, which were outcompeting the bass for habitat space and were able to avoid predation by using cover provided by the weed beds. The low number of green sunfish was attributed to competition from bluegill for habitat space.

4.2.4 North Bog Pond

North Bog Pond has received little management attention. The Fish and Wildlife Service stocked 600 northern pike (5 cm in size) in North Bog Pond in 1976 (USFWS undated b). It was sampled as part of the biological inventory conducted by Rocky Mountain Fisheries Consultants in 1977, but no fish were captured with the 38 m gill net used. However, 188 tiger salamanders (presumably larvae) were caught, indicating that the pond supported a large population of this species (RMFC 1978a). Apparently, no further management actions have been taken.

4.2.5 Havana (South Gate) Pond

Although fish are present in this small pond, probably introduced via natural means, no inventories have been conducted, nor has it been actively managed.

5.0 HISTORY OF AQUATIC RESOURCE CONTAMINATION

5.1 BACKGROUND

Hazardous substances have been produced, stored, disposed, and used at Rocky Mountain Arsenal since it was established in 1942. Most of these substances were transported offsite, or were disposed or released onsite in a manner that does not represent a risk of injury to aquatic resources. Some, however, have been released into aquatic environments, either directly or indirectly, and thus have been--or continue to be--of concern.

A complete characterization of hazardous substances present within RMA and its aquatic environments is hampered in three ways: (1) a very large number of chemicals, compounds, and substances--over 700--have been identified as being associated with the Arsenal; (2) documentation of spills and releases is incomplete; and (3) previous sampling efforts have been neither systematic nor comprehensive. Therefore, a complete data base does not exist for all chemicals possibly present in the RMA environment over the years. Furthermore, much of the existing technical literature for the site does not include a description of sampling and analytical protocols. In cases where protocols are described, they often are below current standards. For these reasons, the reliability and utility of the existing literature are limited with regard to the kinds and amounts of contaminants historically found in the aquatic systems of the Arsenal.

5.2 REPORTED OCCURRENCES OF CONTAMINATION

5.2.1 High Alkalinity in the South Lakes

The first major problem with aquatic resources at RMA apparently was in the late 1940s, when high alkalinity was reported in the South Lakes (except Lake Mary, which had not yet been constructed). A transcript of a 1951 telephone conversation between two Army colonels contains a statement that the Army had "put caustics into the lake . . . and killed the fish" (Willman 1952). This release of caustics probably occurred sometime between 1945 and 1948.

In May 1951, a caustic solution (strength and amount unspecified) was inadvertently released from the chlorine plant operated by Hyman, and reached the lakes via the process water return canal (Army 1951). The resulting alkalinity of 10.5 "destroyed practically all the wildlife in and around the lakes." When informed by the Army of this incident Hyman replied that the release was due to the design of the chlorine plant, and that they would take steps to prevent any further caustic from reaching the lakes in the future (Hyman 1951b). Hyman also noted that the alkalinity of the lake water had decreased enough since the incident (to a pH of between 9.0 and 9.5) to support fish, and that they were making arrangements to stock the lakes with fish. There is no documentation as to species that were present in the lakes prior to the caustic release, nor that the lakes were stocked following the incident.

Hyman (and later Shell) continued to monitor pH in the return water system through the early 1950s. Review of Shell's monitoring reports from 1952 through 1956 indicates that water at the Lake Ladora pumphouse occasionally reached or exceeded a pH of 9.5 during that period. Shell added muriatic acid to the lake system twice in 1955 in an attempt to lower the pH (Shell 1955). It is not clear exactly where Shell added the acid, but it apparently was somewhere within the lakes rather than between the pumphouse and the South Plants.

Several repairs were made to the canal system surrounding the lakes in the early 1950s. Records indicate that Hyman personnel repaired at least three breaks in unspecified ditches to prevent lake contamination (Silber 1953). The ditches carried effluent from the caustic and chlorine plants to Basin A and were repaired where drainage was toward the lakes. The effluent was considered to be "non-toxic contaminated waste carrying variable amounts of salt, caustic, and acid," according to the report's authors. Two of the repairs were on portions of Sand Creek Lateral, and one was on an unnamed contaminated ditch. In none of these descriptions of repairs was it mentioned that contamination to the South Lakes had actually occurred, only that contamination was possible if the condition described was not corrected. The repairs were all done as reimbursable expenditures under the terms of the lease agreement between Hyman and the Army.

5.2.2 Pesticides and Metals in the South Lakes Prior to Sediment Removal

The possibility of chemical problems other than high pH in the South Lakes (again excepting Lake Mary) was indicated in 1951 by increased mortality of waterfowl and aquatic organisms in the lake system (Hyman 1951a). The Army suspected that the lakes had been contaminated with organic compounds from Hyman's manufacturing processes, possibly entering the cooling water system through small leaks in the heat exchangers. This theory was never substantiated, and an inspection by Hyman of their heat exchangers at the time indicated no leaks in the system (Hyman 1951).

The Army reiterated their belief that contamination of the lakes by Hyman's products was responsible for the waterfowl deaths and consequently asked Hyman to solve and correct the problem (Goodall 1952). Accordingly, Hyman labs analyzed various process water and lake water samples in 1952 (Silber 1952). Although they did not detect any of their products, they did report the presence of one or more unidentifiable organic compounds (Hyman 1952c). Hyman also implemented a program to determine whether contaminants could have accidentally been diverted or leaked into the process water line and reportedly took steps to eliminate the possibility of contamination resulting from their processes.

A study by the Fish and Wildlife Service's Denver Wildlife Research Laboratory was conducted in early 1952 to try to determine the cause of high waterfowl mortality (over 1,200 ducks during a period of a few months) at the South Lakes (Sciple 1952). The study involved field and laboratory toxicity experiments using waterfowl from onsite and offsite (control) areas, as well as water and sediment samples from the lakes. Researchers concluded that the mortality was related to a surface-borne agent toxic to the central nervous system. An oily scum was found on the lake surface during the investigation but was not subjected to laboratory analysis. At about the same time, the Toxicology Branch of the Army Chemical Center in Maryland conducted bioassay studies on water from Lower Derby Lake and concluded that the water, exclusive of scum, contained no toxic compounds and was safe for swimming (Bayliss 1952).

The first documented occurrence of pesticides in the South Lakes was in May 1952, when a Shell analysis (Shell Chemical Company had taken over Hyman's lease) detected dieldrin at 1 ppm and aldrin at 68 parts per million (ppm) and in lake surface water and foam respectively (Hyman 1952b). Following this discovery, Shell and Army personnel agreed to alter conditions thought to be contributing to the continued duck mortality at the lakes (U.S. Army 1953). Actions taken included (a) raising the water level in Upper Derby Lake, because of a strong correlation between low water levels (with correspondingly large areas of exposed mud flats) and high mortality, and (b) initiating a program to collect scum from the lakes for analytical purposes. Analysis of the scum in 1953 revealed the presence of dieldrin and aldrin (Hyman 1953b), but concentration levels were not included in the lab report. Two years later, dieldrin concentrations of 261 ppm and 32.7 ppm were found in duck fat and duck livers, respectively (Jensen 1955). However, other lab analyses during the same period did not detect pesticides (Hyman 1953a, Shell 1957). Duck mortality continued, especially when lake water levels were low and large areas of mud flat exposed.

In 1959, the Denver Wildlife Research Laboratory again investigated avian mortality at the Arsenal and estimated that 2,000 ducks had died per year over the previous 10 years (Finley 1959). During the time the study was conducted (April), more than a hundred duck carcasses were found around the shores of Lake Ladora alone. The study team observed that the ecology of the lakes was "grossly out of balance," especially Upper Derby Lake, and that much of the fauna (fish, amphibians, and aquatic insects) normally associated with freshwater lakes in the area was absent. Chemical analyses of sediment samples from Upper Derby Lake showed that the pesticide concentrations were highest in the inlet (480 ppm) where return process water from the South Plants entered, and decreased dramatically with increasing distance away from that point (dieldrin values of 3.0 ppm, 0.3 ppm, and below detection limit respectively). Dieldrin levels in Lower Derby Lake also were lowest at the outlet and away from the central water channel. Based on these data, Finley hypothesized that the pesticides had entered the lakes by the canal from the South Plants area.

Analyses of tissue from dead ducks collected along the shore of Lake Ladora revealed measurable amounts of aldrin and dieldrin, but the Fish and Wildlife Service was unable to conclude that the pesticides had caused the deaths (Finley 1959). Bioassay tests conducted on tadpoles were also part of the study; the results of these tests are discussed in Section 5.4.1 of this report.

As a result of the 1959 study, the Fish and Wildlife Service recommended that the Arsenal take steps to reduce the waterfowl mortality, including keeping the lakes full, removing contaminated sediments from the lake beds, and draining the most contaminated lakes and keeping them dry (USFWS 1960).

High waterfowl mortalities continued to be reported in 1961 and 1962, although the Fish and Wildlife Service estimated that mortality was lower than it had been during the 1950s (Sheldon and Mohn 1962). This was attributed to the fact that the lakes were kept full for a greater portion of the year; mortalities increased whenever Upper Derby Lake was empty. Lab analyses by the Fish and Wildlife Service of dead waterfowl collected along the shores of the South Lakes in March 1962 showed dieldrin concentrations of up to 33 ppm ($\bar{x}$ = 17 ppm, n = 8) in composites of liver and kidney tissue, and up to 20 ppm ($\bar{x}$ = 11 ppm, n = 8) in brain tissue (Sheldon and Mohn 1962).

In 1963, a conference on the lake contamination problem was held at the Arsenal (U.S. Army 1963). Those attending included representatives from the Army, Shell, the Fish and Wildlife Service, and the Colorado State Game, Fish, and Parks Department (now called the Colorado Division of Wildlife). No conclusions were reached as to the cause of the contamination or the parties responsible for it. However, it was agreed that a sampling and analysis program should be implemented to determine the existing level of contamination and to provide a basis for designing appropriate corrective measures.

The sampling and analysis program of South Lakes sediments was conducted by the Fish and Wildlife Service in 1963 and 1964, in conjunction with a program to remove sediments identified as being contaminated (Crabtree and Sheldon 1963) (see Section 5.2.3). Sampling consisted of taking the uppermost layer of lake sediments with a 7.5 cm diameter core at predetermined intervals along a grid system superimposed on Upper Derby, Lower Derby, and Ladora lakes. Samples were taken at 0-5 cm, 5-10 cm, and 10-15 cm depths. Approximately 800 sediment samples were collected from the lakes and were analyzed by a private contract lab (Crabtree et al. 1964). Analytes were limited to aldrin and dieldrin only.

Plant and animal tissue samples also were collected at RMA by the U.S. Fish and Wildlife Service in 1963 (Sheldon et al. 1963). Analyses of these samples showed that the highest levels of aldrin and dieldrin occurred in organisms closely associated with the lakes. For example, waterfowl visceral fat contained up to 2400 ppm dieldrin ($\bar{x}$ = 1266, n = 4), while pheasant visceral fat and deer visceral fat had maximum levels of only 14.4 ppm ($\bar{x}$ = 7.4, n = 3) and < 0.1 ppm (n = 2), respectively. No fish were analyzed.

Shell also collected and analyzed sediment and biota samples during this period. In April 1964, four yellow perch from Lake Mary were composited and analyzed for pesticide content, and low levels of aldrin, dieldrin, endrin, DDT, and DDE were found in both the edible portions and the viscera (Shell 1964a). Sediment samples collected from lakes Ladora and Mary by Shell in 1964 also contained no pesticides above detection limits (Shell 1964b), but sediment samples from Upper and Lower Derby Lakes showed concentrations of up to 183 ppm aldrin, 12.7 ppm dieldrin, 8.3 ppm isodrin, and 10.0 ppm endrin (Shell 1964c). In another analysis conducted during Shell's 1964 sampling program, snails and tadpoles collected in June from Lake Ladora and from either Lower Derby Lake or Upper Derby Lake (the document was unclear which) were found to contain low concentrations of several pesticides (Shell 1964e).

Foam and scum that had collected on weeds in the process water return ditch was sampled in February 1964, and low levels of aldrin (3.5 ppm) and isodrin (0.2-0.3 ppm) were detected (Shell 1964d). There was no indication whether these insecticides had recently been released from the plants area or were already in the process water system and were being recirculated.

5.2.3 Sediment Removal Program

Scraping depths for the South Lakes sediment removal program are shown on U.S. Army record drawings of Upper and Lower Derby lakes (U.S. Army 1964c) and Lake Ladora (U.S. Army 1964b). No documentat on has been found to verify whether the program was carried out as planned. Excavated material was placed in two waste areas directly across Sixth Avenue south of the Derby Lakes.

According to the record drawings, Upper Derby Lake received the most intensive scraping, with 60 cm of sediments removed from the center of the lake and 30 cm of material from the inlet canal where process cooling water was returned from the South Plants (Figure 3-3). The minimum amount removed from the main body of Upper Derby Lake was 7.5 cm, and apparently no sediments were to be excavated from the "eastern arm" of the lake (i.e., east of "E" Street). Most of Lower Derby Lake was scraped to a depth of 7.5, with 15 cm of sediment removed from the deeper parts.

Scraping of Lake Ladora ranged from 7.5 cm to as much as 30 cm in the deepest portion of the lake and in the "Ladora neck", which connects Lower Derby Lake to Lake Ladora. An area in the center (i.e., the deepest part of Lake Ladora was marked on the record drawing with "extra excavation required." It is not known if this area was subsequently re-excavated. A note was made on the drawing that a minimum of 30 cm of material was to be removed from any area below the standing water level. Excavated material was placed in two waste areas south and west of the lake.

Following sediment removal, the lakes were refilled in early 1965, and trees were planted in adjacent areas denuded during the cleanup (U.S. Army 1965). Researchers from the Denver Wildlife Research Center reported that waterfowl mortality around the lakes was lower in 1965 than it previously had been, although 163 carcasses were collected during the first half of the year (King 1967). It was suspected that the continued mortality was occurring because 45 m of ditch connecting Lake Ladora with Lower Derby Lake had not been scraped during the cleanup (Crabtree et al. 1965). Additional waterfowl mortality was noted in this area in January 1966 (Shell 1966b), and a subsequent Shell analysis confirmed that the sediments were contaminated with up to 30 ppm aldrin ($\bar{x}$ = 7 ppm, n = 9). In March 1966, Shell removed approximately 15-20 cm of sediment from the area and dug 133 m of new canal (King 1967).

5.2.4 Pesticides and Metals in the South Lakes Following Sediment Removal

Following the cleanup of Upper Derby, Lower Derby, and Ladora lakes, the Fish and Wildlife Service conducted a restocking program that extended into 1970 (see Section 4.1). After restocking was completed, the Fish and Wildlife Service, the Army, and Shell all conducted various sampling programs to analyze aquatic biota tissue, sediments, and water for pesticides plus a few metals and other selected analytes. Lake Mary was included in these sampling programs, even though it had not been scraped.

Species, tissues, analytes, and sample sizes have varied considerably since post-scraping contaminant monitoring was initiated. However, a few species and analytes have been addressed consistently enough to allow some comparisons to be made. Of greatest value are data for fillets of northern pike, largemouth bass, bluegill, and black bullhead, plus rainbow trout (from Lake Mary only).

General patterns of contaminant distribution and concentration are summarized in the following discussions. Graphs in Appendix A illustrate means and ranges of selected contaminant concentrations in fish fillet tissue. Complete data listings from sampling programs at RMA are presented in Appendix B.

It should be noted that the following discussions and the appendices do not include data for 1984 collected by Rosenlund et al. (1986), because of differences in how the data were analyzed and reported. The results of that study, and roughly concurrent studies of South Lakes sediments by Bergerson et al. (1984) and Myers and Gregg (1984), are described in Section 5.5.

Lake Mary As described above, Lake Mary was not scraped during the sediment removal program of the mid-1960s, but it has been monitored along with the other South Lakes since that time because it is located directly downstream of them and is an important recreational resource at RMA.

A limited tissue sampling program was conducted in 1970, during which a five-fish composite of back bullheads was analyzed for whole body concentrations of pesticides (Spectran 1970). The results showed that the prevalent pesticides in the fish were

DDE at 0.43 ppm and dieldrin at 0.31 ppm. Other values reported were as follows: DDD--0.14 ppm; DDT--0.11 ppm; and aldrin--0.10 ppm. Data on pesticide concentration in Lake Mary water have not been discovered for 1970, but samples taken in 1973 showed both aldrin and dieldrin at less than 1.0 ppb (i.e., below the detection limit) (Shell 1973a).

More intensive sampling of Lake Mary began in 1977, when two rainbow trout whole bodies and twelve fillets were analyzed for pesticides. All twelve fillets had detectable levels of dieldrin ($\bar{x}$ = 0.82 ppm, max = 1.92 ppm). Aldrin, endrin, and DDE also were detected but at lower concentrations. Two water samples taken from Lake Mary by Shell in 1977 had dieldrin values of 0.13 and 0.14 ppb, aldrin at 0.05 and 0.07 ppb, and no detectable endrin (Shell 1977). Dieldrin levels in Lake Mary trout fillets dropped sharply over the next 2 years, with average detected concentrations of 0.25 ppm (max = 0.57 ppm, n = 14) in 1978 and only 0.05 ppm (max = 0.10, n = 13) in 1979. Pesticide concentrations have continued to be very low or undetectable in fish tissue and water samples from Lake Mary.

In contrast to the decrease in pesticides in Lake Mary fish after 1977, mercury levels have remained fairly consistent. For example, mean mercury concentrations reported by Thorne (1982c, 1986) were 0.22 ppm in 1978 (trout, n = 11), 0.26 in 1979 (trout, n = 4); 0.29 (bass, n = 6) and 0.35 (catfish, n = 2) in 1980; 0.58 (bass, n = 12) in 1981; 0.47 (bass, n = 20) in 1982; 0.29 (various species, n = 7) in 1983; and 0.33 (bass, n = 11) and 0.21 (bluegill, n = 8) in 1984. These calculated mean values for 1981 and 1982 do not include high "outlier" values of 6.55 ppm and 2.50 ppm, respectively.

<u>Lake Ladora</u> Sampling of fish tissue from Lake Ladora has been more consistent than that for Lake Mary or the Derby Lakes. Dieldrin concentrations in bass fillets fluctuated between 1970 and 1979, although the general trend has been downward since the peak year of 1971 ($\bar{x}$ = 3.01 ppm, max = 4.7 ppm, n = 4). Means of detected values had declined to 1.42 ppm in 1972 (max = 2.7,

n = 4) and to 0.36 ppm in both 1973 (max = 0.42, n = 2) and 1975 (max = 1.04, n = 6). From 1979 through 1984, dieldrin levels in Lake Ladora bass fillets continued to drop, and other fish sampled had similarly low values. Detected dieldrin values by species in 1984 were as follows: largemouth bass, $\bar{x}$ = 0.02 ppm (max = 0.03, n = 4); black bullhead, $\bar{x}$ = 0.04 ppm (max = 0.07, n = 10); bluegill, $\bar{x}$ = 0.04 ppm (max = 0.08, n = 15); northern pike, $\bar{x}$ = 0.02 ppm (max = 0.03, n = 8). Concentrations of other pesticides in Lake Ladora biota have been quite low, with few actual "hits" documented (see Appendix B).

Mercury levels in Lake Ladora fish tissues varied sufficiently to obfuscate any trends (see Appendix A-7). For black bullheads, means have ranged from 0.25 ppm (max = 0.37, n = 10) in 1981 to 0.73 ppm (max = 0.94, n = 8) in 1983, but with no mercury detected in 1984 (n = 10). For largemouth bass, the documented range has been from 0.40 ppm in both 1977 (n = 1) and 1982 (max = 0.49, n = 6) to a high of 1.12 ppm (max = 1.77, n = 3) in 1980. Actually, the reported maximum concentration for bass fillets in 1980 was 15.3 ppm, which would increase the means to 4.66 ppm if this outlier value were included. Data for other contaminants in Lake Ladora biota are too scarce to bear discussion, but see Appendix B for a listing.

<u>Lower Derby Lake</u> Fish tissues from Lower Derby Lake have been sampled regularly only since 1977 (see Appendix A-3). In that year, bass and bullhead composite samples had dieldrin concentrations of 0.89 and 3.19 ppm, respectively. In 1979, sample means for bass and bullhead fillets had declined to 0.42 ppm (max = 0.50, n = 6) and 0.39 (max = 0.65, n = 6), respectively, while northern pike fillets averaged 0.27 ppm (max = 0.53, n = 6). In 1984, means were 0.28 ppm (max = 0.46, n = 7) for bass, 0.13 ppm (max = 0.21, n = 5) for bluegill, 0.08 ppm (max = 0.08, n = 12) for bullheads, and 0.07 ppm

(max = 0.10, n = 10) for pike. Only one bass was analyzed. As in lakes Mary and Ladora, values of other pesticides in fish tissue have been lower than values for dieldrin.

Mercury concentrations in fish tissue from Lower Derby Lake have fluctuated, with no trends apparent (Appendix A-7). Reported mercury levels in bullheads have ranged from 0.26 ppm (max = 0.31, n = 10) in 1980 to 0.64 ppm (max = 1.30, n = 8, excluding an outlier value of 9.0) in 1981. Means of detected values in 1984 were 0.53 ppm (max = 0.92, n = 12) for bullheads; 0.39 ppm (max = 0.71, n = 7) for bass; and 0.69 ppm (max = 1.30, n = 10) for pike.

Upper Derby Lake No contaminant data have been found for Upper Derby Lake since the sediment scraping program in the mid 1960s. This probably is because Upper Derby Lake does not represent a recreation resource and frequently is dry.

Other RMA Water Bodies Aldrin was detected in a sample of First Creek water, taken near the Arsenal's North Boundary, in June 1973 at a level of 5 ppb (Shell 1973a). A sediment sample taken at the same time and location showed a level of 62 ppb dieldrin; due to interference, the aldrin level was not reported (Shell 1973b).

In 1977, aldrin was detected at a level of 0.016 ppb in a sample of water from the Highline Canal (U.S. Army 1977f). This level was lower than levels in any of the other samples from the South Lakes taken at the time, which ranged from 25-155 ppt for the pesticides aldrin, dieldrin, and lindane.

Dieldrin was detected in bass and bullhead tissue (whole body analysis) collected from the Toxic Storage Yard Pond in 1977 at levels of 0.26 and 0.22 ppm, respectively (McBride 1978). Endrin, mercury, DDE, and DDT were also detected, although at much lower levels.

5.2.5 Source of Pesticides in Aquatic Systems at RMA

The previous discussions may leave the impression that the presence of pesticides in aquatic resources at RMA has resulted solely from accidental spills or releases associated with manufacturing, storage, or disposal onsite. This is not necessarily true, however, because First Creek and the ditches and canals that feed into the South Lakes flow through agricultural, industrial/commercial, and residential areas where the use of pesticides is widespread. In addition, the Army has used a variety of insecticides, herbicides, and soil sterilants as part of their ongoing maintenance operations at RMA. For example, aquatic weeds in Lake Ladora were controlled with copper sulfate in 1943-1945 (U.S. Army undated b), and in Lake Mary with sodium arsenite in 1962 (U.S. Army undated c). Malathion has been used to control mosquitoes in ditches and canals near the South Lakes since at least 1979 (U.S. Army 1979), and spraying with DDT is reported as early as 1945 (U.S. Army 1945, 1948a).

5.3 TOXICOLOGY STUDIES OF AQUATIC VERTEBRATES AT RMA

Two experimental studies were conducted at RMA to examine the effects of various surface waters on aquatic life. The first was an aquarium study that used mud and algae from Upper Derby Lake as the "contamination" source and tadpoles of leopard and chorus frogs as the test organisms. The second study used black bullhead survival in North Bog Pond as a basis for assessing whether it could support fish life and perhaps should be stocked. The two studies are described below.

5.3.1 Tadpole Study

The tadpole study was described by Finley (1959) of the U.S. Fish and Wildlife Service in his report on waterfowl mortality on the Arsenal. Four groups of tadpoles were placed in unaerated aquaria; three were test aquaria and one was a control aquarium. Results are described below.

- Aquarium 1 contained 25 tadpoles in uncontaminated pond water (source not documented) with Upper Derby Lake mud added. Tadpoles were fed uncontaminated algae (source also not documented). Total mortality occurred after 11 days.

- Forty-two tadpoles were placed in Aquarium 2, which contained uncontaminated pond water (source not documented). Tadpoles were fed algae from Upper Derby Lake. All died after 12 days.

- Upper Derby Lake water was used in Aquarium 3, in which 50 tadpoles were placed and fed uncontaminated algae (source not documented). Total mortality occurred after 50 days.

- Aquarium 4 was designated as the control. Sixty-six tadpoles were placed in uncontaminated water and fed uncontaminated algae (neither source documented). All of the controls died after 51 days.

In general, the study was poorly executed and documented. For example, several potentially important parameters were not reported in the results. These included the source of uncontaminated pond water and algae, as well as the type and amount of algae placed in each aquarium. The last parameter could significantly affect oxygen availability for the tadpoles. No aeration was provided to the aquaria during the study, nor were any environmental variables such as temperature, dissolved oxygen concentration, pH, or hardness monitored.

Because so many important parameters were not measured during the tadpole study, reliable conclusions cannot be drawn. However, the results do suggest that Upper Derby Lake sediments and algae were toxic to tadpoles, but that Upper Derby Lake water was not. This could indicate that the contaminants responsible for death were relatively insoluble in water, but were sequestered in the sediments and accumulated by algae.

5.3.2 Black Bullhead Study

The second study, conducted in 1977 by Rocky Mountain Fisheries Consultants under contract to the Army (RMFC 1978a), involved placing fifteen black bullheads captured from Lower Derby Lake and the Rod and Gun Club Pond into North Bog Pond. Five of the fish were held in minnow traps. Three of these died after 144 hours, and the other two were dead after 168 hours. Ten of the fish were held in 0.6 m x 0.6 m x 1.2 m cages. Five of these died after 48 hours, and the remaining five were dead after 120 hours. Water temperatures were considerably lower during the test involving the cages, due to decreased air temperatures. The size of the minnow traps was not given, but if standard-sized traps were used, they contained at most 5 percent of the volume of the cages.

The tests and important environmental parameters were poorly documented, monitored, and reported, limiting the value of any data collected. Observations concerning the condition of moribund fish revealed discolored skin, gill anemia, capillary dilation, and hemorrhaging, along with edema of the dorsal musculature and vent. These conditions would seem to indicate that some type of irritant or toxicant was present in the water at the time of the study. Also, none of the 600 small northern pike stocked in North Bog Pond in 1976 were captured during a survey in 1977 (RMFC 1978a), further suggesting that the pond was an inhospitable environment. Nonetheless, the consultants did note that North Bog Pond supported large populations of aquatic insects and larval tiger salamanders at the time of the bullhead study. Thus, it is not clear whether the fish mortality was due to chemical contaminants or some other factor.

5.4 USE OF RMA CONTAMINANT DATA IN AQUATIC RESOURCE MANAGEMENT

Contaminant data were initially used in an attempt to determine the cause of waterfowl mortality in the South Lakes and to assess the extent of chemical contamination in aquatic environments at RMA. More recently, the data have also been used to formulate a policy on recreational use of the lakes.

In 1975, the Army determined that levels of aldrin and dieldrin in fish in the South Lakes were higher than limits for human consumption established by the World Health Organization (WHO) (U.S. Army 1975a), which were between 0.02 and 0.2 ppm. As a result, the Army's Life Sciences Laboratory Division recommended that pesticide levels in fish from the lake be carefully monitored in the future.

In 1977, analyses of rainbow trout from Lake Mary showed levels of dieldrin above the Food and Drug Administration (FDA) limit for human consumption, which at the time was 0.7 ppm (U.S. Army 1977c-1977f). These levels existed despite removal of large amounts of sediment when Lake Mary was enlarged and deepened in 1967 and 1975 (Mack 1967, Schmidt 1975). The Army decided that trout caught from the lake should not be eaten (U.S. Army 1977e), and a catch-and-release policy was instituted.

Whole body analyses of fish collected later in 1977 from lakes Mary, Ladora, and Lower Derby also showed relatively high levels of dieldrin. Concentrations were highest in fish from Lower Derby Lake, and especially in black bullheads. Aldrin, endrin, DDT, DDE, and DIMP were also detected, but at lower levels (McBride 1978). These findings resulted in the imposition of a catch-and-release policy for all freshwater lakes on the Arsenal, beginning in 1978 (U.S. Army 1981a).

In 1981, the Fish and Wildlife Service expressed concern to the Colorado Department of Health (CDH) over the high dieldrin levels, which exceeded the Food and Drug Administration's established action level of 0.3 ppm for the edible portion of fish (Minnich 1981). In response, CDH proposed the establishment of an interagency task group, composed of wildlife biologists, toxicologists, and epidemiologists, to study the problem and make recommendations to the Army regarding cleanup and exposure reduction (Ouimette 1981).

A review by the U.S. Fish and Wildlife Service of historical contaminant levels in fish noted that bullheads contained the highest levels of dieldrin (Jacobsen 1981). It was surmised that dieldrin remained mainly in the bottom sediments, with which bullheads are likely to have more contact than the other game fish present. The report also noted that levels of contaminants had generally decreased over the years, except for mercury which apparently had increased. The Fish and Wildlife Service recommended that the lakes remain closed to angling except on a strictly enforced catch-and-release basis.

5.5 RECENT STUDIES OF SOUTH LAKES CONTAMINATION

The natural resource injury and remedial investigation/feasibility studies currently being conducted at RMA by Army and Shell include contaminant assessments of South Lakes sediments, water, and selected aquatic biota (notably waterfowl and fish). Initial findings of those efforts are not included in this report, which was intended instead to focus on existing literature. This section summarizes the results of a detailed study titled "Final Report, Contaminants in Aquatic Systems at the Rocky Mountain Arsenal, 1984" published by the Fish and Wildlife Service in January 1986 (Rosenlund et al. 1986). Also briefly described are sediment investigations of the South Lakes conducted for the Army in 1982 and 1983 (Myers et al. 1983, Myers and Gregg 1984, Bergerson et al. 1984).

5.5.1 Water Quality of RMA Lakes

Analyses by Rosenlund et al. (1986) of water samples from Lower Derby, Ladora, and Mary lakes revealed no values above detection limits for aldrin, dieldrin, endrin, or mercury. Detection limits were in the parts per billion range for mercury and tenths of a part per billion for organochlorine pesticides. Similar results had been obtained in 1983 by Bergerson et al. (1984). Myers and Gregg (1984) found dieldrin at a concentration of 0.02 ppb in a sample of water from Lake Mary, but not from Lake Ladora. Their study of the other South Lakes (Myers et al. 1983) did not include water samples.

Rosenlund et al. (1986) reported that Lakes Mary and Ladora were clear, with Secchi disc visibilities of 2 to more than 5 m. Lower Derby was turbid, with only 1 m of visual penetrability. Temperature, pH, and dissolved oxygen values for all three lakes were normal for their elevation, location, and depth. No abnormal fish mortality was noted.

5.5.2 Pesticide and Mercury Residues in South Lakes Sediment

An investigation of aldrin, dieldrin, endrin, and mercury in sediments of Upper and Lower Derby lakes and the Rod and Gun Club Pond was conducted in 1982 by the U.S. Army Engineer Waterways Experiment Station (Myers et al. 1983). The study's goals were to confirm the presence of aldrin, dieldrin, endrin, and mercury in lake sediments and surrounding canals and to determine their concentration and distribution. The data showed that the contaminants were widely distributed in the sediments, with the highest concentrations in the upper layers of sediment, in organic materials, near the inflow channels, and in the deepest water. Lower concentrations were generally found deeper in the sediments, in clastics, and in shallow water. Lower Derby Lake and the main body of Upper Derby Lake showed higher levels of the contaminants tested than the Rod and Gun Club Pond and the eastern arm of Upper Derby Lake. Based on these results, it was recommended that the lakes be drawn down and sediment removed from the areas in Upper and Lower Derby lakes with the highest concentrations. This program has not been undertaken.

A similar study of Lake Mary and Lake Ladora sediments was conducted by the Waterways Experiment Station in 1983 (Myers and Gregg 1984). This study also showed that pesticide concentrations were highest in the upper layers of sediment. Areas with highest concentrations of pesticides and mercury in Lake Ladora were the inlet channel, the "inlet pool" where the channel enters the lake, and an area near the middle of the lake. No such distinct patterns were evident for Lake Mary.

Aldrin was the most ubiquitous of the four contaminants tested by Myers and Gregg (1984), being present above the detection limit in 117 of the 145 total samples (81 percent) and 49 of the 50 upper layer (0-30 cm) samples (98 percent). Dieldrin also was found in 98 percent of the upper layer sediments, while endrin was detected in only 58 percent. Mercury was present in 91 of the 145 total samples (63 percent) and was nearly uniformly distributed throughout the 91.5 cm of bottom material collected. Mean concentrations above the detection limit reported by Myers and Gregg (1984) for lakes Mary and Ladora were 0.0017 ppm aldrin, 0.0006 ppm dieldrin, and 0.15 ppm mercury.

Bergerson et al. (1984) studied sediment deposition rates and contaminant levels in lakes Ladora and Lower Derby in 1983. Analytes were mercury, aldrin, and dieldrin; Cesium-137 was used to date the sediments. The sediment samples used in their tests were collected from the deepest area of Lower Derby Lake and in the shallow upper neck of Lake Ladora.

The results of the Bergerson et al. (1984) studies are poorly presented in their report to the Army, but four conclusions can be drawn. First, aldrin and dieldrin were generally below detection limits or present only in very low concentrations in both Lower Derby and Ladora. Aside from one hit of 2 ppm in

Lower Derby and four hits of 1.5, 1.8, 2.7, and 6.4 ppm in Ladora, aldrin concentrations detected averaged only 0.04 ppm (n = 4) and 0.09 ppm (n = 15) for the two lakes, respectively. Aldrin was detected in 31 percent of the samples from Lower Derby and 70 percent of those from Ladora. Dieldrin was above the detection limit in only 20 percent of the samples from Lower Derby and 30 percent of those from Ladora. Values of dieldrin above the detection limit averaged only 0.03 ppm (n = 9) for Lower Derby and 0.14 ppm (n = 8) for Ladora. The highest dieldrin levels were 0.10 ppm in Lower Derby and 0.46 ppm in Ladora.

Second, the studies showed that mercury was virtually ubiquitous in the sediments, being present above the detection limit in 98 percent of the samples from Lower Derby and 81 percent of those from Ladora. Mercury concentrations above the detection limit averaged 0.6 ppm and 0.06 ppm for Lower Derby and Ladora, respectively.

Third, the Cesium-137 sampling showed sediments from essentially every year, including "decimal dates" as old as 1958.7 and 1959.2 for the two cores from Lower Derby and of 1958.2 and 1962.3 for the two cores from Ladora. This underscores that the lakes were not thoroughly scraped during the 1964-65 cleanup.

Fourth, re-suspension tests performed as part of the studies showed that aldrin and dieldrin, but not mercury, were introduced into the water column when water + sediment was agitated. However, concentrations quickly dropped below detection limits as the sediments settled out.

5.5.3 Pesticide and Mercury Residues in South Lakes Biota

The Fish and Wildlife Service's ongoing studies of aquatic biota at RMA became markedly more sophisticated and complex in 1984, with a greater variety of organisms examined and a far more thorough presentation and discussion of data. As with previous

Fish and Wildlife Service studies, the 1984 program continued to heavily emphasize only a few contaminants, specifically mercury, aldrin, dieldrin, and endrin.

The more intensive investigation probably was prompted by anticipated cleanup of the site, based on the following quote from the report:

> When contaminated bottom sediments are removed from RMA lakes, aquatic species found to be heavily contaminated in 1984 could be monitored . . . to document the success of the program. (Rosenlund et al. 1986:7)

The Rosenlund et al. (1986) studies addressed lakes Mary, Ladora, and Lower Derby. Upper Derby Lake "had been dewatered for several years, although in 1985 it was full again," and therefore was not sampled. Organisms sampled included six fish species--northern pike, largemouth bass, bluegill, black bullhead, channel catfish, and carp; two amphibians--bullfrogs and "toads;" five groups of aquatic invertebrates--dragonflies, damselflies, chironomids, crayfish, and snails, plus "plankton;" and four species of aquatic macrophytes, referred to in the 1986 report as American pondweed, leafy pondweed, northern watermilfoil, and coontail.

Sampling was conducted five times during 1984 (late May/early June, early-mid July, mid-late August, late September/early October, and mid November) in order to determine any seasonal variations. Each lake was divided into quarters for sampling, and four areal subsamples were recombined ("pooled") to provide a single composite sample for each lake. Sampling resulted in a total of 247 aquatic samples, of which 173 were analyzed. This discrepancy in numbers was not explained. Approximately 13 percent of the analyzed samples (i.e., 22) were submitted as replicate pairs for quality control. The replicates were not marked as such. Laboratory results were then analyzed statistically, using Pearson correlation coefficients to determine significance at the $P < 0.10$ level.

The results of the Rosenlund et al. (1986) studies are summarized below by water body.

Lower Derby Lake Analyses by Rosenlund et al. (1986) of 47 aquatic biota (fish, amphibian, invertebrate, plankton, and macrophyte) samples from Lower Derby Lake showed that mercury, dieldrin, and aldrin were all widespread, being found in 100, 85, and 72 percent of the samples, respectively. Mercury was present in the highest concentrations, with eight of twelve fish fillets above the 1.0 ppm FDA guideline. These values were found in pike, bass, and adult bullhead fillets, while bluegill, carp, and young-of-year bullhead fillets were all below 1.0 ppm. Fish viscera, amphibians, crayfish, aquatic insects, aquatic snails, plankton, and macrophytes also were below 1.0 ppm mercury.

Although widespread, dieldrin was above the FDA guideline of 0.3 ppm in only one bluegill fillet composite sample. Values above 0.3 ppm also were detected in plankton and the viscera of pike and bass. Aldrin was found above the 0.3 ppm FDA guideline in only one bass viscera sample. Levels in fillets were very small. Endrin was detected in only 13 percent of the samples, and none was above 0.3 ppm. All of the measurable endrin levels were in bass or pike viscera.

Lake Ladora None of the three pesticides was widespread in Lake Ladora biota; only 15 percent, 14 percent, and 8 percent of the samples were above detection limits for aldrin, dieldrin, and endrin, respectively. Only dieldrin was found at levels above 0.3 ppm, this from bass and bullhead viscera.

In contrast, mercury was widely distributed in Lake Ladora biota, with only 9 percent below the detection limit (all from invertebrates). Fillets of pike, bass, and some bluegills were well above the 1.0 ppm FDA guideline for mercury, as were bass viscera (no pike viscera were analyzed). Values also were above 1.0 ppm in plankton, some insects, and all macrophytes.

Lake Mary Dieldrin was the most widespread pesticide measured in Lake Mary, with 79 percent of the biota samples above the detection limit. The highest values were in channel catfish viscera (0.527 ppm) and fillets (0.402 ppm). In contrast, viscera and fillets of bass and bluegills were well below the 0.3 ppm FDA guideline for dieldrin. Rosenlund et al. (1986) attributed this difference to the older age and higher fat content of the catfish than the two centrarchids. Dieldrin levels in the invertebrate, plankton, and macrophyte samples were all very low.

Aldrin and endrin were present in fewer of the Lake Mary biota samples and in smaller amounts. Only 40 percent had values above the detection limit for aldrin, and none was above the 0.3 ppm FDA guideline. Endrin was detected in only 15 percent of the samples, and none was above 0.3 ppm. For both aldrin and endrin, channel catfish viscera and fillets had the highest values, although these were low.

Mercury was present in 91 percent of the biota samples. The mean concentration for all samples was 0.23 ppm, well above the 0.1 ppm FDA guideline. Highest concentrations were in bluegill and bass fillets, followed by bass viscera, catfish fillets, macrophytes, damselflies, and plankton. Other biota samples had much lower mean values.

6.0 SUMMARY

The aquatic habitats on Rocky Mountain Arsenal, especially the South Lakes, have the potential to support diverse ecosystems and productive fisheries. Problems caused by chemical contamination, variation in water levels, and the introduction of undesirable fish species have tended to disrupt the ecosystems and lower this potential. The effects of chemical contamination were especially apparent early in the Arsenal's existence. Concern for the biological quality of the lake system seemed to parallel the growth of environmental awareness in America, starting in the 1950s and continuing through the 1960s and 1970s. During this time, increasing attention was paid to preventing and mitigating contamination and to improving aquatic habitats, especially where sport fishing was concerned.

In general, management activities have been successful in creating and maintaining desirable fisheries. The put-and-take rainbow trout fishery in Lake Mary provided many hours of recreation to anglers. Introductions of northern pike in Lake Ladora and Lower Derby Lake and of largemouth bass in all the lakes have created successful and self-sustaining fisheries and helped to control the populations of bullhead and bluegill.

Attempts at cleaning up the South Lakes by removing sediment have not been entirely successful. Although levels of principal contaminants are low enough to not cause duck or fish mortalities, or apparently even to interfere with gross ecosystem functioning, values above FDA guidelines for human consumption continue to occur in some biotic tissues. Mercury is nearly ubiquitous in the aquatic biota, including the fillets of game fish. Organochlorine pesticides also are widespread, but far fewer samples were above FDA action levels in 1984 than was the case for mercury.

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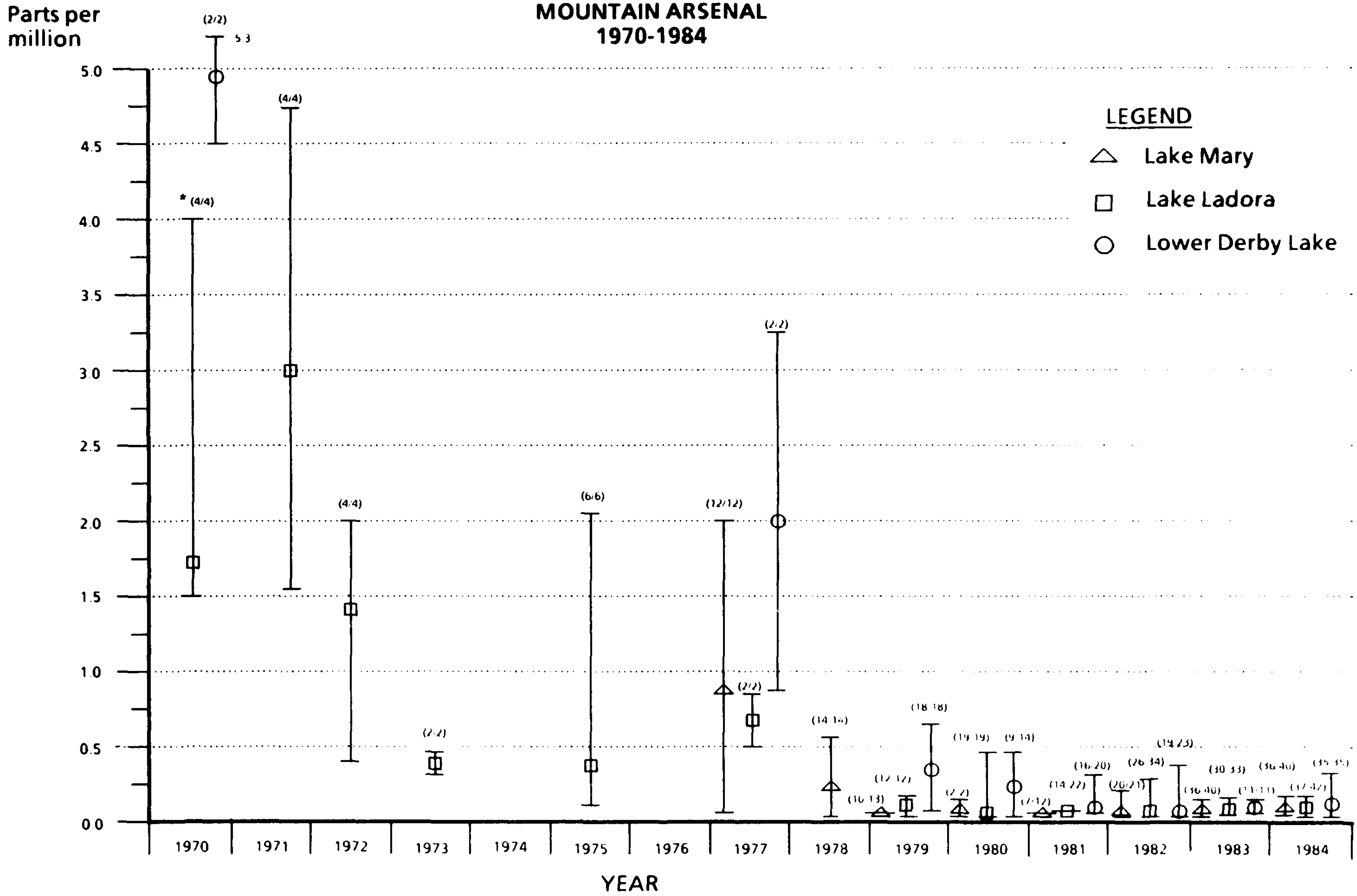
APPENDIX A

MEANS AND RANGES OF SELECTED CONTAMINANTS IN FISH TISSUES AT ROCKY MOUNTAIN ARSENAL

Figure A-1

† MEANS AND RANGES OF DIELDRIN CONCENTRATIONS DETECTED IN FISH TISSUE (FILLET ONLY) FROM LAKES MARY, LADORA, AND LOWER DERBY AT ROCKY MOUNTAIN ARSENAL 1970-1984

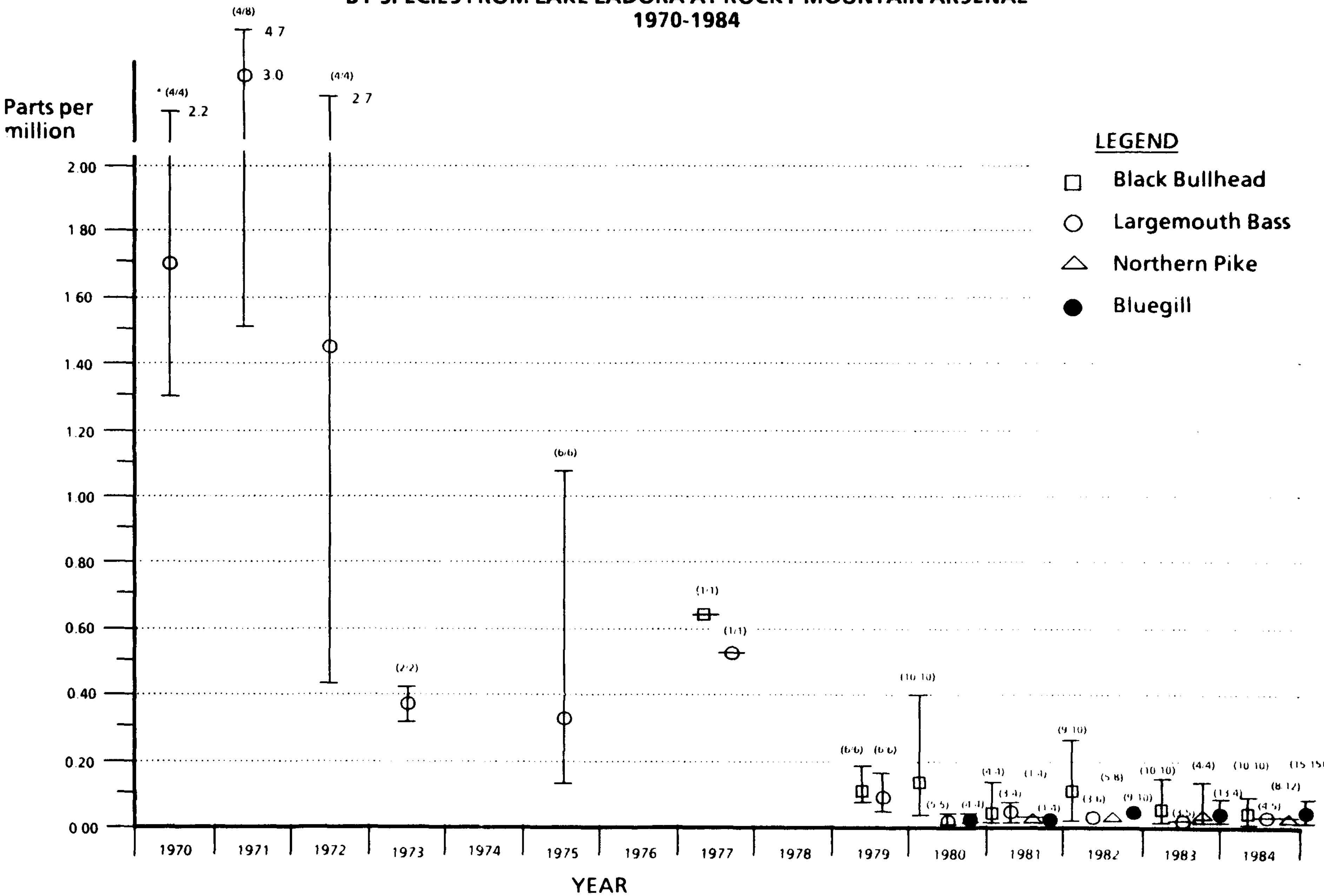


† Calculated from values above detection limits

* Number of samples with concentrations above detection limits / total sample size

Figure A-2

† MEANS AND RANGES OF DIELDRIN CONCENTRATIONS DETECTED IN FISH TISSUE (FILLET ONLY) BY SPECIES FROM LAKE LADORA AT ROCKY MOUNTAIN ARSENAL 1970-1984

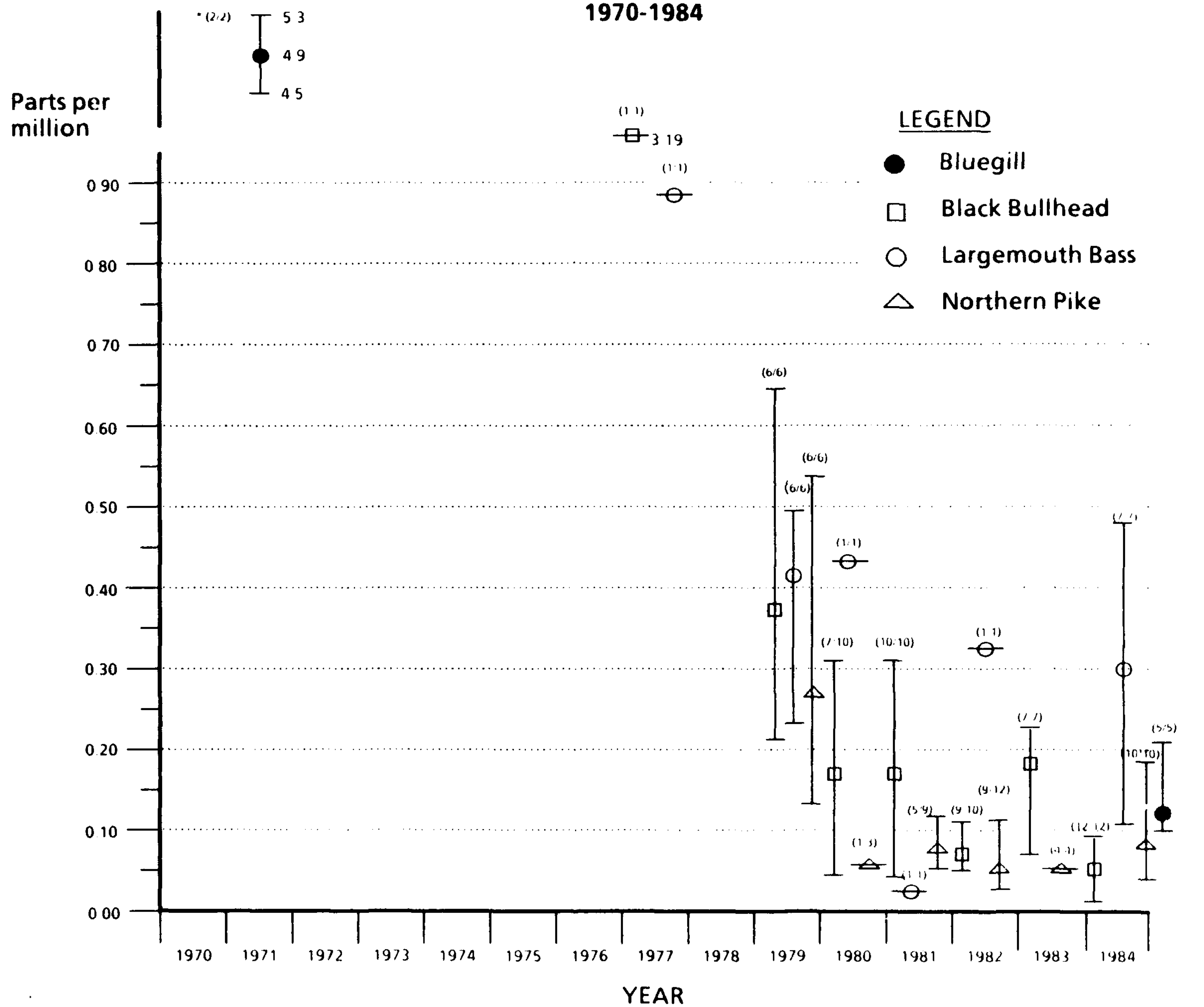


† Calculated from values above detection limits

* Number of samples with concentrations above detection limits / total sample size

Figure A-3

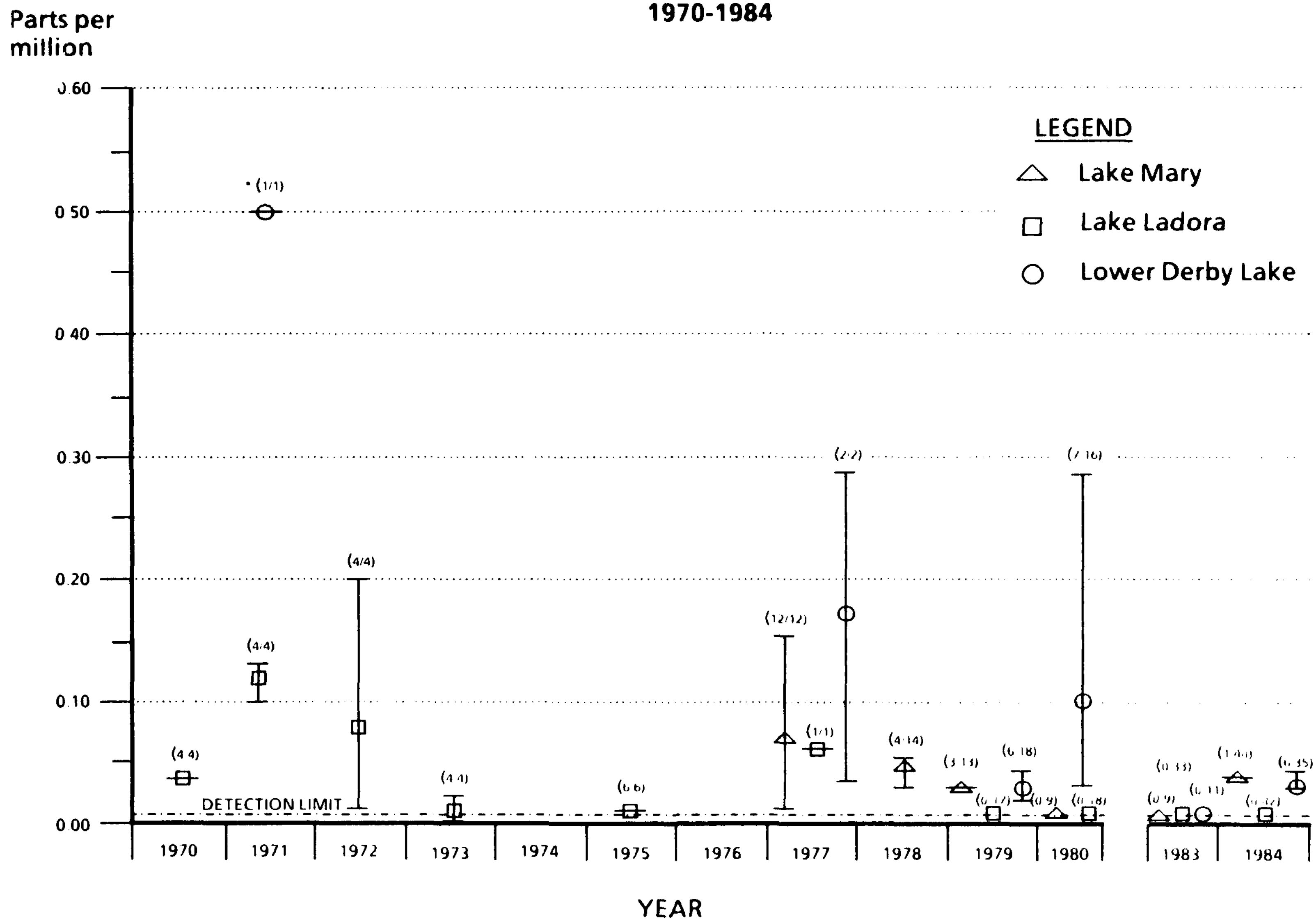
† MEANS AND RANGES OF DIELDRIN CONCENTRATIONS DETECTED IN FISH TISSUE (FILLET ONLY) BY SPECIES FROM LOWER DERBY LAKE, ROCKY MOUNTAIN ARSENAL 1970-1984



† Calculated from values above detection limits
* Number of samples with concentrations above detection limits / total sample size

Figure A-4

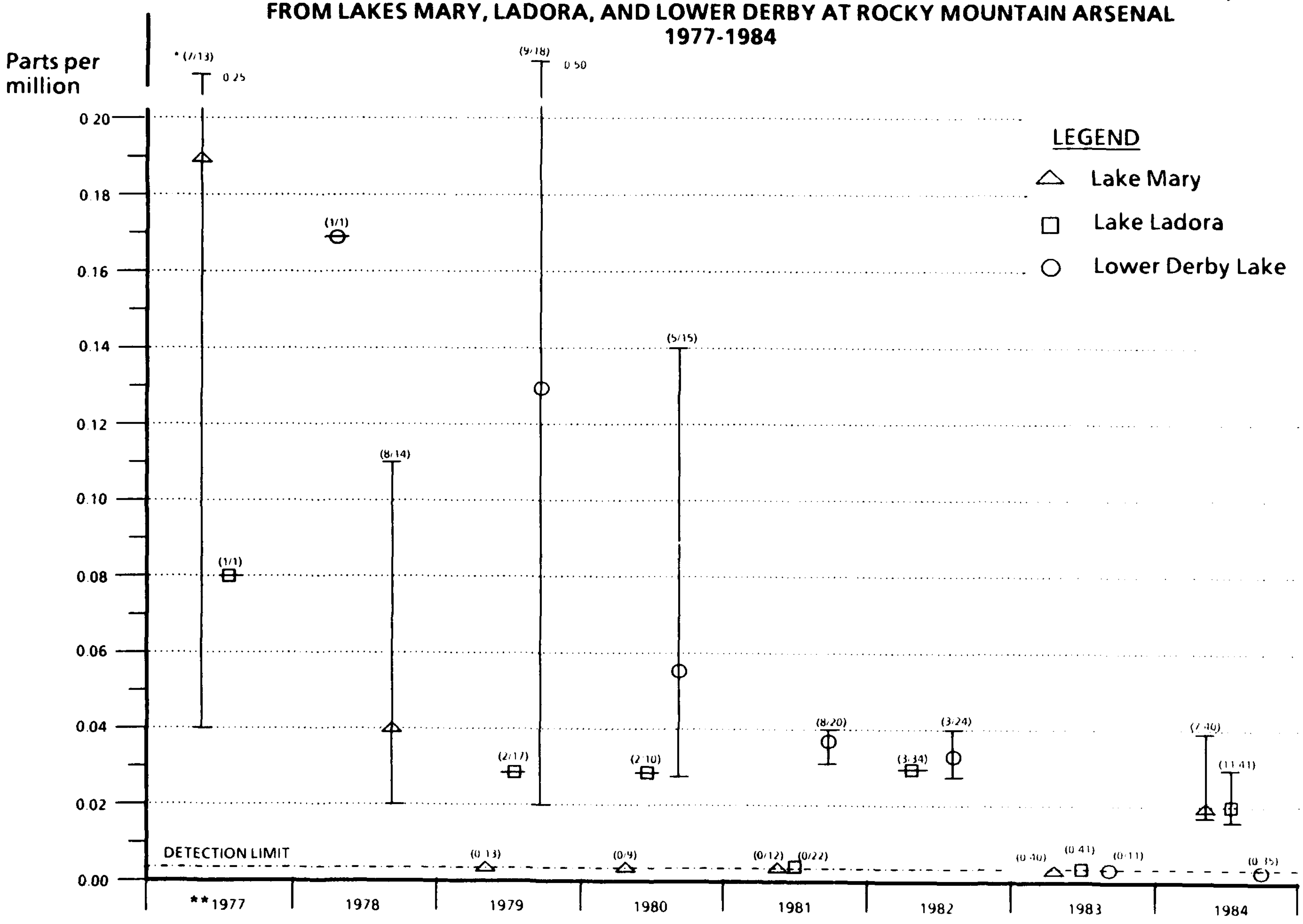
† MEANS AND RANGES OF ALDRIN CONCENTRATIONS DETECTED IN FISH TISSUE (FILLET ONLY) FROM LAKES MARY, LADORA, AND LOWER DERBY AT ROCKY MOUNTAIN ARSENAL 1970-1984



† Calculated from values above detection limits
* Number of samples with concentrations above detection limits / total sample size

Figure A-5

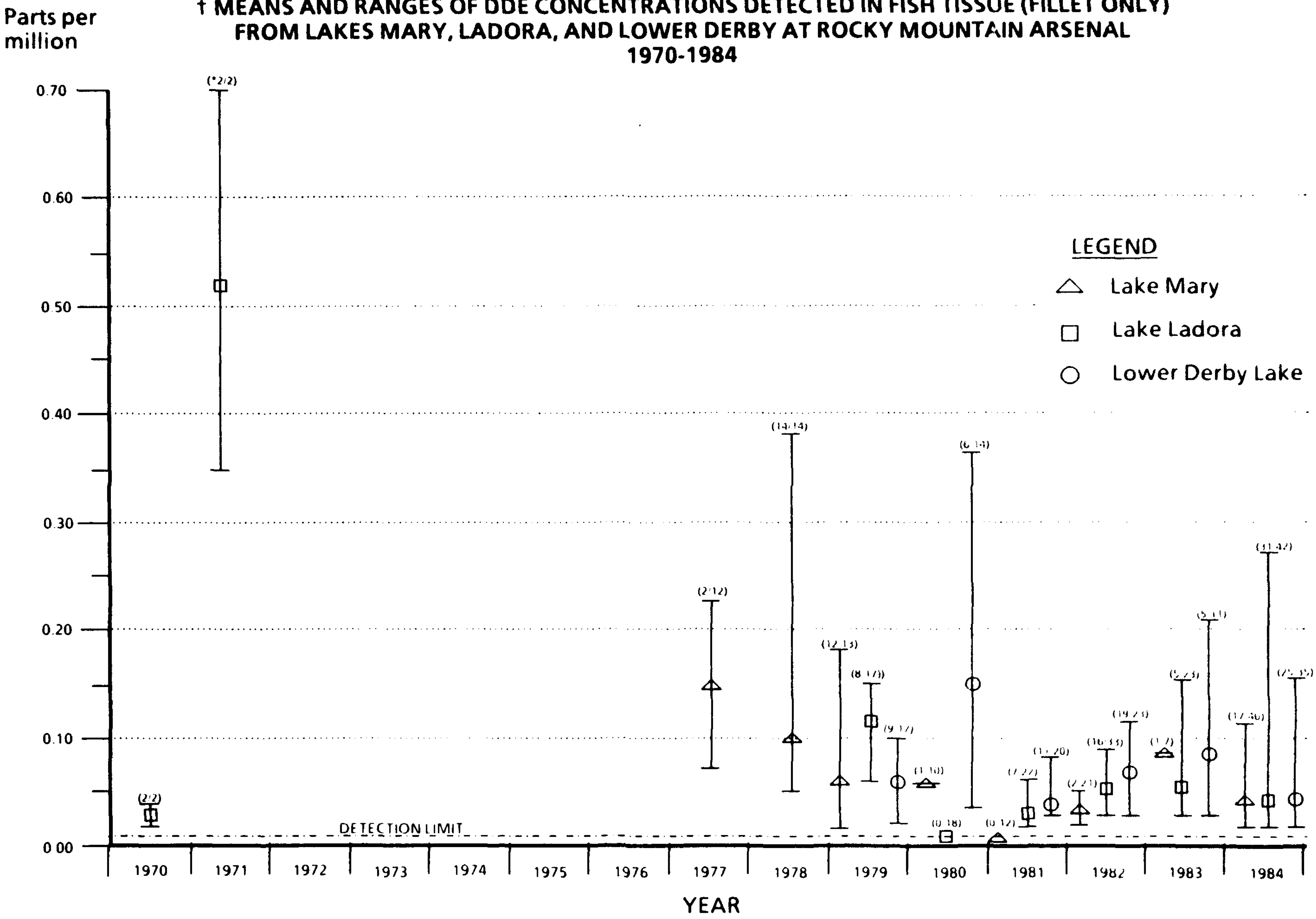
† MEANS AND RANGES CONCENTRATIONS OF ENDRIN DETECTED IN FISH TISSUE (FILLET ONLY) FROM LAKES MARY, LADORA, AND LOWER DERBY AT ROCKY MOUNTAIN ARSENAL 1977-1984



† Calculated from values above detection limits
* Number of samples with concentrations above detection limits / total sample size
** Earliest documented data

Figure A-6

† MEANS AND RANGES OF DDE CONCENTRATIONS DETECTED IN FISH TISSUE (FILLET ONLY) FROM LAKES MARY, LADORA, AND LOWER DERBY AT ROCKY MOUNTAIN ARSENAL 1970-1984

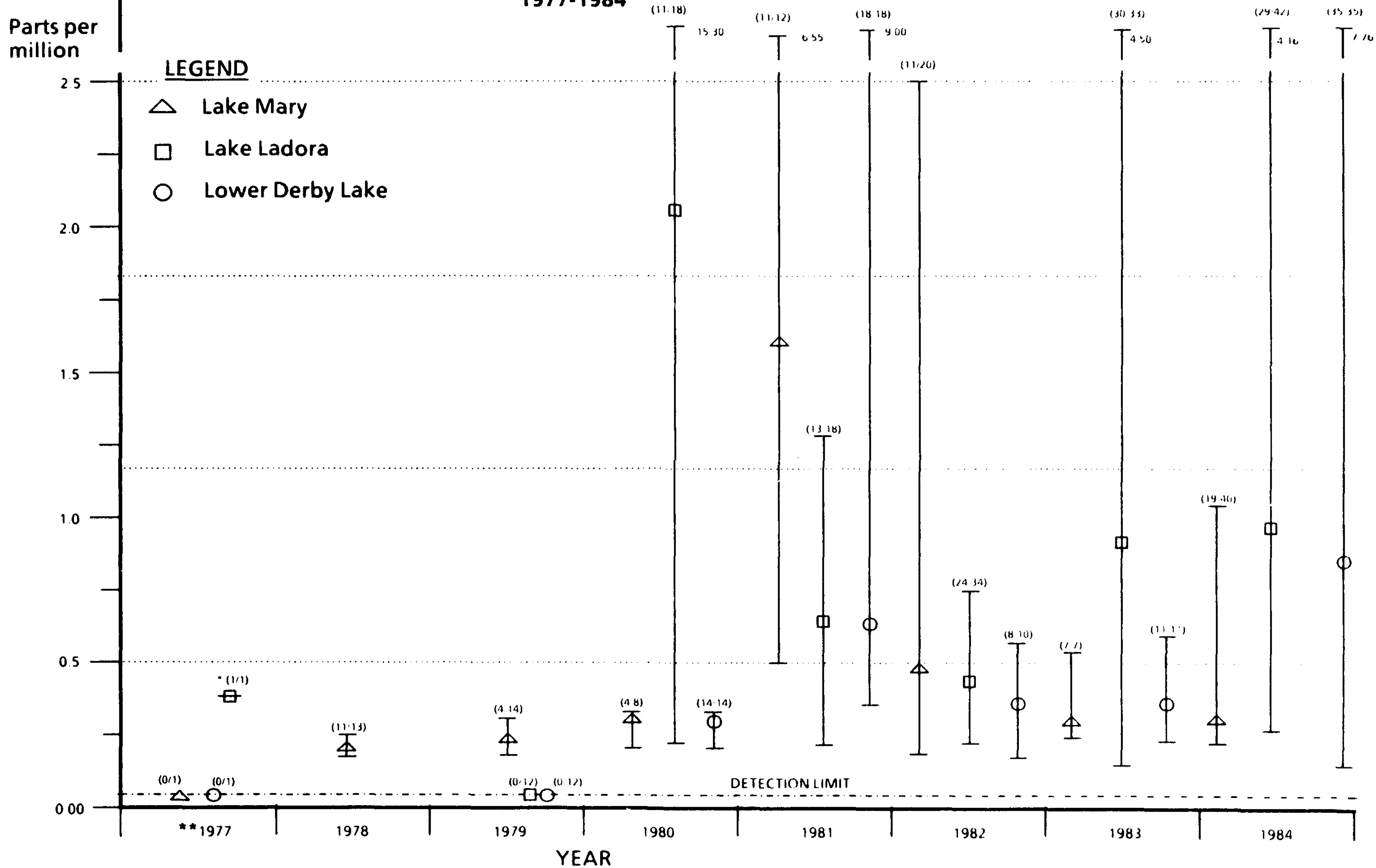


† Calculated from values above detection limits

* Number of samples with concentrations above detection limits / total sample size

Figure A-7

† MEANS AND RANGES OF MERCURY CONCENTRATIONS DETECTED IN FISH TISSUE (FILLET ONLY) FROM LAKES MARY, LADORA, AND LOWER DERBY AT ROCKY MOUNTAIN ARSENAL 1977-1984



† Calculated from values above detection limits
* Number of samples with concentrations above detection limits / total sample size
** Earliest documented data

APPENDIX B

RESULTS OF CONTAMINANT ANALYSES OF AQUATIC BIOTA AT ROCKY MOUNTAIN ARSENAL, 1959-1984

APPENDIX B

CONTENTS

Table B-1 Mercury concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1977	Lower Derby	Bl.bullhead, fillet	BDL
	Ladora	Bl.bullhead, fillet	BDL
		L.bass, fillet	0.40
	Mary	C.catfish, fillet	BDL
	Toxic Yard	Bl.bullhead, fillet	BDL
		L.bass, fillet	0.38
1978	Mary	R.trout, fillet	2 BDL
		"	5 at 0.25
		"	7 at 0.20
	South Lakes	macrophyte, tops	3 BDL
		macrophyte, roots	3 BDL
		leeches/snails	BDL
		Bl.bullhead, whole	2 BDL
		L.bass, whole	BDL
		"	0.4
		frogs/toads, whole	5 BDL
		heron feathers	2 at 0.002
		"	0.001
1979	Lower Derby	Bl.bullhead, fillet	6 BDL
		L.bass, fillet	6 BDL
		N.pike, fillet	6 BDL
	Ladora	Bl.bullhead, fillet	6 BDL
		L.bass, fillet	6 BDL
		N.pike, fillet	6 BDL
	Mary	R.trout, fillet	10 BDL
		"	0.25
		"	0.32
		"	0.26
		"	0.21
1980	Lower Derby	Bl.bullhead, fillet	2 at 0.28
		"	0.24
		"	2 at 0.22
		"	3 at 0.31
		"	0.27
		"	0.21
		Bluegill, fillet	0.36
		L.bass, fillet	0.38
		N.pike, fillet	0.64
		"	0.28
		"	0.29
	Ladora	Bl.bullhead, fillet	7 BDL

Table B-1 Mercury concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1980	Ladora (cont.)	Bl.bullhead, fillet	0.56
		"	0.38
		"	0.29
		Bluegill, fillet	0.78
		"	0.70
		"	0.74
		"	0.68
		L.bass, fillet	0.26
		"	1.33
		"	1.77
		"	15.30
	Mary	C.catfish, fillet	BDL
		"	0.35
		L.bass, fillet	4 BDL
		"	0.32
		"	0.21
		"	0.35
1981	Lower Derby	Bl.bullhead, fillet	0.76
		"	2 at 0.61
		"	1.30
		"	2 at 0.48
		"	0.44
		"	9.00
		"	0.35
		"	0.59
		L.bass, fillet	0.44
		N.pike, fillet	0.63
		"	2 at 0.49
		"	2 at 0.45
		"	1.04
		"	0.76
		"	1.18
		"	1.00
	Ladora	Bl.bullhead, fillet	3 BDL
		"	0.23
		"	0.37
		"	0.25
		"	0.20
		"	0.26
		"	0.21
		"	0.22
		Bluegill, fillet	4 BDL
		L.bass, fillet	2 BDL
		"	0.47
		"	0.46
		N.pike, fillet	1.30

Table B-1 Mercury concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1981	Ladora (cont.)	N.pike, fillet	2 at 1.10
		"	1.00
	Mary	L.bass, fillet	BDL
		"	3 at 0.59
		"	5.85
		"	0.63
		"	0.51
		"	0.58
		"	0.55
		"	2 at 0.57
		"	6.55
1982	Lower Derby	Bl.bullhead, fillet	2 BDL
		"	2 at 0.25
		"	0.16
		"	0.39
		"	0.56
		"	0.36
		"	0.47
		"	0.27
		L.bass, fillet	0.40
		N.pike, fillet	BDL
		"	0.36
		"	0.53
		"	0.74
		"	0.40
		"	0.81
		"	0.61
		"	0.52
		"	0.97
		"	1.60
		"	1.80
		"	0.80
	Ladora	Bl.bullhead, fillet	4 BDL
		"	0.74
		"	0.76
		"	0.71
		"	0.72
		"	0.75
		"	0.54
		Bluegill. fillet	5 BDL
		"	0.56
		"	0.47
		"	0.35
		"	0.44
		"	0.40

Table B-1 Mercury concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Ladora (cont.)	L.bass, fillet	BDL
		"	0.27
		"	0.49
		"	2 at 0.48
		"	0.30
		N.pike, fillet	0.24
		"	0.21
		"	2 at 0.30
		"	2 at 0.22
		"	0.23
		"	0.26
	Mary	C.catfish, fillet	BDL
		L.bass, fillet	9 BDL
		"	2.50
		"	2 at 0.24
		"	4 at 0.22
		"	0.30
		"	2 at 0.39
		"	0.19
1983	Lower Derby	N.pike, fillet	0.36
			0.37
			0.47
			0.58
		B.bullhead, fillet	0.21
			0.26
			0.29
			0.33
			0.34
			0.40
			0.41
	Ladora	N.pike, fillet	0.88
			0.89
			1.23
			4.50
		L.bass, fillet	0.64
			0.73
			0.75
			0.79
			1.05
		Bluegill, fillet	BDL
			0.14
			0.15
			0.24
			0.28
			0.34
			0.35

Table B-1 Mercury concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1983	Ladora (cont.)	Bluegill, fillet	0.40
			0.42
			0.44
			0.45
			0.53
			0.93
			1.80
		B.bullhead, fillet	2 BDL
			0.60
			0.64
			0.66
			0.70
			0.72
			0.73
			0.86
			0.94
	Mary	L.bass, fillet	2 at 0.22
			0.23
			0.27
			0.30
		Bluegill, fillet	0.28
		C.catfish, fillet	0.52
1984	Lower Derby	N.pike, fillet	0.21
			0.38
			0.47
			0.49
			0.50
			0.60
			0.63
			0.92
			1.17
			1.30
			7.76
		L.bass, fillet	0.14
			0.26
			0.33
			0.36
			0.42
			0.55
			0.71
		Bluegill, fillet	0.29
			0.36
			0.48
			2 at 0.66
		Bl.bullhead, fillet	0.22
			0.27

Table B-1 Mercury concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1984	Lower Derby (cont.)	Bl.bullhead, fillet	0.28
			0.34
			0.41
			0.42
			0.43
			0.49
			0.81
			0.90
			2 at 0.92
	Ladora	N.pike, fillet	0.33
			0.35
			0.45
			0.50
			0.52
			0.54
			0.59
			1.01
			1.25
			1.30
			1.36
			4.16
		L.bass, fillet	0.33
			0.61
			0.76
			0.82
			1.19
		Bluegill, fillet	3 BDL
			0.27
			3 at 0.40
			2 at 0.43
			0.48
			0.50
			0.60
			0.90
			1.40
			1.70
		B.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	11 BDL
			2 at 0.28
			3 at 0.30
			3 at 0.33
			0.46
			0.80
			0.90
		Bluegill, fillet	2 BDL
			5 at 0.20

Table B-1 Mercury concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1984	Mary (cont.)	Bluegill, fillet	0.22
			0.24
			0.25
		C.catfish, fillet	10 BDL

[1] data sources: Rosenlund (1982); Thorne (1982c, 1986); USA (1981b).
[2] single entries may represent composites of variable or unknown size.

Table B-2 Arsenic concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1978	South Lakes	Aquatic plants	5.00
1980	Mary	L.bass, fillet	3 BDL
		"	2 at 2.10
		"	2.00
		"	2.20

[1] data sources: Rosenlund (1982), Thorne (1982c).
[2] single entry represents a composite of unknown size.

Table B-3 Cadmium concentrations[1].

Date	Location	Material Tested	Concentration (ppm)
1978	Mary	R.trout, fillet	11 BDL
		"	1.62
		"	1.52
		"	1.01

[1] data source: Thorne (1982c).

Table B-4 Copper concentrations[1].

Date	Location	Material Tested	Concentration (ppm)
1978	South Lakes	macrophyte, tops	21.5
		"	22.3
		"	25.8
		macrophyte, roots	28.8
		"	23.2
		"	38.0
		Bl.bullhead, whole	BDL
		"	90.9
		frogs/toads, whole	14.1
		"	9.7
		"	17.5
		"	13.1
		"	15.9
		heron, feathers only	30.9
		"	26.8
		"	23.9

1 data source: Thorne et al. (1979).
2 single entries may represent composites of unknown or variable size.

Table B-5 Dieldrin concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1959	effluent canal	sediment	0.5
	Upper Derby canal	sediment	11.0
	Upper Derby inlet	sediment	480.0
	Upper Derby	sediment	3.0
		"	0.3
		"	0.0
	Upper Derby inlet	water	0.002
	Upper Derby	algae & pondweed	2.7
	Lower Derby	water & foam	BDL
		"	0.5
		foam	9.0
		sediment	0.7
		"	BDL
		"	0.2
	Lower Derby outlet	sediment	0.4
		"	0.04
	Ladora	sediment	BDL
1960	Upper Derby	algae	45.0
		"	17.0
		pondweed seeds	1.0
		snails	64.0
		"	32.0
	Lower Derby	algae	21.0
		snails	77.0
		tiger salamander	117.0
	Ladora	algae	39.0
		"	23.0
		cattail	5.0
		snails	22.0
		"	28.0
		leeches	83.0
1962	South Lakes	snails	57.0
		tiger salamander	14.0
1963	South Lakes	snails	20.0
		"	11.0
		leech	14.0
	Upper Derby	terrestrial veg.	1.2
	Ladora	macrophyte	17.6
		"	14.0
		"	4.5

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1964	Upper Derby	sediment	12.7
		"	8.6
		"	1.4
		"	1.2
		"	2 at < 1.0
	Lower Derby	sediment	2.0
		"	1.0
		"	5.0
		"	3 at < 1.0
		snails, except shells	29.0
		snails, shells only	9.6
	Ladora	snails, except shells	7.6
		snails, shells only	2.4
		tadpoles	0.7
	Mary	water	0.0005
		Y. perch, fillet	0.52
		Y. perch, viscera	3.7
1970	Inlet to Ladora	water	0.6
		"	0.8
	Ladora	water	0.7
		Bluegill, whole	3.5
		L.bass, nonedible	2.2
		"	2.7
		L.bass, fillet	1.5
		"	2.2
		"	1.3
		"	1.9
		L.bass, whole	3.94
	Mary	Bl.bullhead, whole	0.31
	Highline Canal	water	0.04
1971	Lower Derby	Bluegill, fillet	5.3
		"	4.5
	Ladora	water	0.0006
		"	< 0.0010
		"	0.0025
		L.bass, fillet	1.80
		"	4.70
		"	1.54
		"	4.00
		"	2.42
		"	3.11
		"	3.57
		"	4.64
	Highline Lateral	water	< 0.001

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1972	Lower Derby Inlet	water	0.005
	Ladora Inlet	water	< 0.0002
	Ladora	water	< 0.0002
		L.bass, fillet	2.0
		"	0.44
		"	0.55
		"	2.7
		"	0.057
		"	0.071
1973	Lower Derby Inlet	water	2.5
	Lower Derby	water	< 0.005
	Ladora Inlet	water	< 0.005
	Ladora	water	0.0003
		"	2 at < 0.005
		"	3 at < 0.001
		sediment	0.025
		"	2 at .042
		L.bass, fillet	2 at 0.31
		"	0.42
		"	0.32
		"	0.46
		"	2 at 0.39
		"	0.35
	Mary	water	2 at < 0.005
		"	2 at < 0.001
		sediment	0.11
		"	0.09
	First Creek	water	< 0.005
		sediment	2.08
	South Lakes	Bluegill	10.2
		L.bass	1.1
		"	1.2
		"	2 at 0.6
		"	0.5
		"	1.6
		"	2.1
1974	Lower Derby	sediment	0.2
	Ladora	sediment	0.2
1975	Ladora	L.bass, fillet	0.31
		"	0.27
		"	0.15
		"	0.22
		"	0.16
		"	1.04

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1977	Lower Derby	water	133 ng/l
	Ladora	water	83 ng/l
	Mary	water	56 ng/l
	Rod & Gun	water	25 ng/l
	Lower Derby	Bl.bullhead, fillet	3.19
		L.bass, fillet	0.89
	Ladora	Bl.bullhead, fillet	0.69
		L.bass, fillet	0.51
	Mary	R.trout, whole	2.36
		"	0.73
		R.trout, fillet	2 at 0.12
		"	0.14
		"	0.19
		"	1.69
		"	0.06
		"	0.05
		"	1.92
		"	1.49
		"	1.15
		"	2.00
		"	0.92
	Toxic Yard	Bl.bullhead, fillet	0.20
		L.bass, fillet	0.26
1978	Mary	R.trout, fillet	3 at 0.11
		"	0.12
		"	2 at 0.50
		"	0.32
		"	2 at 0.16
		"	0.57
		"	0.34
		"	0.07
		"	2 at 0.22
	South Lakes	macrophyte, tops	0.06
		"	0.10
		macrophyte, roots	2 BDL
		"	0.08
		leeches/snails	0.16
		"	0.04
		Bl.bullhead, whole	0.69
		"	3.19
		L.bass, whole	0.51
		"	0.89
		frogs/toads, whole	0.15
		"	0.08
		"	3.95
		"	0.70

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1978	South Lakes (cont.)	frogs/toads, whole	0.07
		heron, except feathers and skin	BDL
		"	1.23
		"	6.20
1979	Lower Derby	Bl.bullhead, fillet	0.31
		"	0.48
		"	0.29
		"	0.65
		"	0.40
		"	0.21
		L.bass, fillet	0.49
		"	0.24
		"	0.48
		"	2 at 0.50
		"	0.29
		N.pike, fillet	0.25
		"	0.53
		"	0.15
		"	0.39
		"	0.13
		"	0.18
	Ladora	Bl.bullhead, fillet	2 at 0.11
		"	0.10
		"	0.16
		"	0.20
		"	0.09
		L.bass, fillet	0.19
		"	0.13
		"	0.12
		"	0.11
		"	0.06
		"	0.07
	Mary	R.trout, fillet	3 BDL
		"	2 at 0.06
		"	3 at 0.04
		"	2 at 0.05
		"	0.10
		"	2 at 0.03
1980	Lower Derby	Bl.bullhead, fillet	3 BDL
		"	4 at 0.12
		"	0.44
		"	0.06
		"	0.27
		Bluegill, fillet	BDL

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1980	Lower Derby (cont.)	L.bass, fillet	0.46
		N.pike, fillet	2 BDL
		"	0.07
	Ladora	Bl.bullhead, fillet	0.15
		"	0.40
		"	0.06
		"	2 at 0.10
		"	0.05
		"	0.13
		"	0.26
		"	0.11
		"	0.16
		L.bass, fillet	2 at 0.03
		"	3 at 0.05
		Bluegill, fillet	2 at 0.05
		"	0.04
		"	0.03
	Mary	C.catfish, fillet	0.16
		"	0.22
		L.bass, fillet	BDL
		"	0.11
		"	0.10
		"	2 at 0.03
		"	0.06
		"	0.08
1981	Lower Derby	Bl.bullhead, fillet	0.31
		"	2 at 0.10
		"	0.14
		"	0.23
		"	0.29
		"	0.16
		"	0.30
		"	0.09
		"	0.05
		L.bass, fillet	0.03
		N.pike, fillet	4 BDL
		"	0.06
		"	0.12
		"	2 at 0.10
		"	0.08
	Ladora	Bl.bullhead, fillet	BDL
		"	2 at 0.09
		"	2 at 0.06
		"	0.13
		"	0.04
		"	0.05

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1981	Ladora (cont.)	Bl.bullhead, fillet	0.08
		"	0.03
		Bluegill, fillet	3 BDL
		"	0.03
		L.bass, fillet	BDL
		"	0.05
		"	0.06
		"	0.03
		N.Pike, fillet	3 BDL
		"	0.03
	Mary	L.bass, fillet	5 BDL
		"	0.05
		"	3 at 0.03
		"	0.08
		"	2 at 0.06
1982	Lower Derby	Bl.bullhead, whole	0.11
		"	(trace)
		Bl.bullhead, fillet	BDL
		"	0.06
		"	3 at 0.05
		"	0.11
		"	0.09
		"	2 at 0.07
		"	0.10
		L.bass, fillet	0.34
		N.pike, fillet	3 BDL
		"	3 at 0.05
		"	0.11
		"	3 at 0.07
		"	0.04
		"	0.03
	Ladora	water	2 at < 10 ng/l
		sediment	
		sediment, 0.0-1.0 ft	< 0.0002
		"	0.0011
		"	0.0030
		sediment, 1.0-2.0 ft	2 at < 0.0002
		"	0.0060
		sediment, 2.0-3.0 ft	2 at < 0.0002
		"	0.0070
		Bl.bullhead, fillet	BDL
		"	2 at 0.04
		"	0.07
		"	0.19
		"	0.11
		"	0.09

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Ladora (cont.)	Bl.bullhead, fillet	0.13
		"	0.14
		"	0.24
		Bluegill, fillet	BDL
		"	3 at 0.04
		"	3 at 0.06
		"	0.07
		"	0.08
		"	0.15
		L.bass, fillet	3 BDL
		"	0.03
		"	2 at 0.05
		N.pike, fillet	3 BDL
		"	2 at 0.04
		"	2 at 0.03
		"	0.07
	Mary	water	20 ng/l
		sediment, 0.0-1.0 ft	0.004
		"	0.006
		sediment, 1.0-2.0 ft	0.001
		"	< 0.0002
		sediment, 2.0-3.0 ft	2 at 0.001
		C.catfish, fillet	0.22
		L.bass, fillet	BDL
		"	5 at 0.05
		"	0.06
		"	0.07
		"	2 at 0.08
		"	0.16
		"	6 at 0.04
		"	0.11
		"	0.10
		"	0.12
1983	Lower Derby	N.pike, fillet	0.04
			3 at 0.05
		Bl.bullhead, fillet	0.08
			0.09
			0.10
			2 at 0.11
			0.12
			0.21
	Ladora	N.pike, fillet	2 at 0.03
			0.04
			0.12
		L.bass, fillet	2 BDL
			3 at 0.03

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1983	Ladora (cont.)	Bluegill, fillet	BDL
			3 at 0.03
			4 at 0.04
			0.05
			0.06
			0.07
			0.08
			2 at 0.09
		Bl.bullhead, fillet	0.03
			0.04
			0.05
			0.06
			0.07
			0.08
			0.09
			2 at 0.10
			0.11
	Mary	L.bass, fillet	5 BDL
		Bluegill, fillet	0.10
		C.catfish, fillet	0.16
1984	Lower Derby	N.pike, fillet	2 at 0.04
			0.05
			2 at 0.06
			2 at 0.07
			0.09
			2 at 0.10
		L.bass, fillet	0.11
			0.14
			0.31
			0.35
			0.36
			0.41
			0.46
		Bluegill, fillet	0.04
			0.10
			0.14
			0.16
			0.21
		Bl.bullhead, fillet	0.02
			4 at 0.03
			0.04
			2 at 0.05
			0.08
			0.10
			0.11
			0.18

Table B-5 Dieldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1984	Lake Ladora	N.pike, fillet	4 BDL
			6 at 0.02
			2 at 0.03
		L.bass, fillet	BDL
			2 at 0.02
			2 at 0.03
		Bluegill, fillet	2 at 0.02
			4 at 0.03
			3 at 0.04
			4 at 0.05
			0.07
			0.08
		Bl.bullhead, fillet	0.02
			3 at 0.03
			2 at 0.04
			0.05
			0.06
			2 at 0.07
	Mary	L.bass, fillet	4 BDL
			12 at 0.02
			3 at 0.03
			0.04
		Bluegill, fillet	0.08
			3 at 0.11
			3 at 0.12
			0.14
			2 at 0.17
		C.catfish, fillet	2 at 0.07
			2 at 0.08
			0.10
			2 at 0.11
			0.12
			0.4
			0.22

[1] data sources: Dean (1970, 1971, 1973); Ferentchak (1970); Finley (1959); Knaus (1973); McBride (1978); Mullan (1975d); Rosenlund (1982); Sheldon et al. (1963); Sheldon and Mohn (1962); Shell (1964a,c,e; 1973a,c; 1974); Spectran Laboratories (1970); Thorne (1982c, 1986); Thorne et al. (1979); USA (1971b,c,d; 1972, 1973a; 1975b; 1977e.f.g; 1981b; 1983d); USFWS (1961); Whitt and McBride (1977).

[2] single entries may represent composites of variable or unknown size.

Table B-6 Aldrin concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1959	effluent canal	sediment	3.5
	Upper Derby Canal	sediment	84.0
	Upper Derby	sediment	18.0
		"	2.6
		"	0.3
	Upper Derby inlet	water	0.002
	Upper Derby	algae and pondweed	3.1
	Lower Derby inlet	foam	5.0
		water and foam	BDL
		"	1.5
	Lower Derby	sediment	21.0
		"	2 at 0.6
	Lower Derby outlet	sediment	1.0
		"	0.01
	Ladora	sediment	0.05
		"	0.6
1960	Upper Derby	algae	34.0
		"	73.0
		snails	9.0
		"	38.0
	Lower Derby	algae	3.0
	Ladora	algae	2.0
1962	South Lakes	snails	2 at 5.0
		tiger salamander	0.1
1963	South Lakes	snails	BDL
		"	3.7
		leech	< 0.1
	Ladora	macrophyte	26.4
1964	Upper Derby	sediment	156.0
		"	183.0
		"	103.0
		"	6.5
		"	3.3
		"	31.0
	Lower Derby	sediment	9.8
		"	10.5
		"	17.4
		"	3 at < 1.0
		snails, except shells	0.27
		snails, shells only	0.06
		tadpoles	0.04

Table B-6 Aldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1964	Mary	Y.perch, fillet	< 0.01
		Y.perch, viscera	0.03
1970	Highline Canal	water	0.01
	Inlet to Ladora	water	0.20
		"	0.30
	Ladora	water	0.20
		Bluegill, whole	5 at 0.01
		L.bass, nonedible	2 at 0.09
		L.bass, fillet	4 at 0.04
		L.bass, whole	5 at 0.08
	Mary	Bl.bullhead, whole	5 at 0.01
1971	Lower Derby	Bluegill, fillet	0.5
	Ladora	water	0.0003
		L.bass, fillet	2 at 0.1
		"	0.14
		"	0.13
1972	Lower Derby inlet	water	0.0002
	Ladora inlet	water	< 0.0002
	Ladora	"	< 0.00002
		L.bass, fillet	0.20
		"	0.04
		"	0.01
		"	0.06
		L.bass	2 at 0.013
1973	Lower Derby inlet	water	2.7 ppb
	Lower Derby	water	< 5.0 ppb
	Ladora inlet	water	< 5.0 ppb
	Ladora	water	2 at < 0.005
		"	< 0.2 ppb
		"	3 at < 0.001
		sediment	0.015
		"	0.052
		L.bass, fillet	0.0055
		"	0.0064
		"	0.0059
		"	0.0025
		"	0.0120
		"	0.0083
	Mary	water	2 at < 0.005
		"	2 at < 0.001
		sediment	0.010
		"	0.015
	First Creek	water	< 5.0 ppb

Table B-6 Aldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1973	First Creek (cont.)	sediment	1.85
	South Lakes	Bluegill	0.44
		L.bass	0.06
		"	0.03
		"	2 at 0.02
		"	0.04
		"	0.07
		"	0.18
1974	Lower Derby	sediment	0.02
	Ladora	sediment	0.03
1975	Ladora	L.bass, fillet	6 at < 0.01
1977	Lower Derby	water	25 ng/l
		L.bass, fillet	0.04
		Bl. bullhead, fillet	0.29
	Ladora	water	26 ng/l
		Bl. bullhead, fillet	0.06
	Highline Lateral	water	16 ng/l
	Lower Derby	L.bass, whole	0.04
	Mary	R.trout	0.16
		R.trout, fillet	0.04
		"	3 at < 0.01
		"	0.08
		"	2 at 0.03
		"	2 at 0.16
		"	0.09
		"	0.18
		"	2 at 0.06
1978	Mary	R.trout, fillet	10 BDL
		"	2 at 0.05
		"	0.03
		"	0.06
	South Lakes	macrophyte, tops	0.050
		"	2 BDL
		macrophyte, roots	3 BDL
		leeches/snails	21.0
		"	0.10
		Bl.bullhead, whole	0.06
		"	0.29
		L.bass, whole	BDL
		"	0.04
		frogs/toads, whole	4 BDL
		"	1.16

Table B-6 Aldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1978	South Lakes (cont.)	heron, except feathers and skin	3 BDL
1979	Lower Derby	Bl.bullhead, fillet	6 BDL
		L.bass, fillet	6 BDL
		"	3 at 0.03
		"	0.02
		"	0.04
		"	0.05
	Ladora	Bl.bullhead, fillet	6 BDL
		L.bass, fillet	6 BDL
		N.pike, fillet	5 BDL
	Mary	R.trout, fillet	10 BDL
		"	3 at 0.04
1980	Lower Derby	Bl.bullhead, fillet	5 BDL
		"	2 at 0.03
		"	0.28
		"	0.06
		"	2 at 0.04
		Bluegill, fillet	BDL
		L.bass, fillet	0.31
		N.pike, fillet	3 BDL
	Ladora	Bl.bullhead, fillet	10 BDL
		Bluegill, fillet	4 BDL
		L.bass, fillet	4 BDL
	Mary	C.catfish, fillet	2 BDL
		L.bass, fillet	7 BDL
1981	Lower Derby	N.pike, fillet	9 BDL
		L.bass, fillet	1 BDL
		Bl.bullhead, fillet	10 BDL
	Ladora	N.pike, fillet	4 BDL
		L.bass, fillet	4 BDL
		Bluegill, fillet	4 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	12 BDL
1982	Lower Derby	N.pike, fillet	12 BDL
		L.bass, fillet	1 BDL
		Bl.bullhead, fillet	10 BDL
	Ladora	water	2 at < 10 ng/l
		sediment, 0.0-1.0 ft	2 at < 0.0002
		"	0.002
		sediment, 1.0-2.0 ft	2 at < 0.0002
		"	0.002
		sediment, 2.0-3.0 ft	2 at < 0.0002

Table B-6 Aldrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Ladora (cont.)	sediment, 2.0-3.0 ft	0.0009
		N.pike, fillet	8 BDL
		L.bass, fillet	6 BDL
		Bluegill, fillet	10 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	water	< 10 ng/l
		sediment, 0.0-1.0 ft	0.002
		"	0.003
		sediment, 1.0-2.0 ft	2 at < 0.0002
		sediment, 2.0-3.0 ft	2 at < 0.0002
		L.bass, fillet	20 BDL
		C.catfish, fillet	1 BDL
1983	Lower Derby	N.pike, fillet	4 BDL
		Bl.bullhead, fillet	7 BDL
	Ladora	N.pike, fillet	4 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	14 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	5 BDL
		Bluegill, fillet	1 BDL
		C.catfish, fillet	1 BDL
1984	Lower Derby	N.pike, fillet	10 BDL
			0.02
		L.bass, fillet	2 BDL
			3 at 0.02
			2 at 0.03
		Bluegill, fillet	5 BDL
		Bl.bullhead, fillet	12 BDL
	Ladora	N.pike, fillet	12 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	15 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	20 BDL
		Bluegill, fillet	10 BDL
		C.catfish, fillet	9 BDL
			0.03

[1] data sources: Dean (1970, 1971, 1973); Ferentchak (1970); Finley (1959): Knaus (1973); McBride (1978); Mullan (1975d); Sheldon et al. (1963); Sheldon and Mohn (1962); Shell 1964a,c,e; 1973a,c; 1974); Spectran Laboratories (1970); Thorne (1982c, 1986); Thorne et al. (1979); USA (1971b,c,d; 1972, 1973a; 1975b; 1977c,d,e,f,g; 1981b,d; 1983d); USFWS (1961); Whitt and McBride (1977).

[2] single entries may represent composites of variable or unknown size.

Table B-7 Endrin concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1964	Lower Derby	sediment	6 at < 1.0
		snails, except shells	1.1
		snails, shells only	0.36
	Upper Derby	sediment	10.0
		"	6.8
		"	1.0
		"	3 at < 1.0
	Ladora	snails, except shells	0.5
		snails, shells only	0.22
		tadpoles	0.06
	Mary	Perch, fillet	0.04
		Perch, viscera	0.11
1977	Lower Derby	Bl.bullhead, fillet	0.17
	Ladora	Bl.bullhead, fillet	0.08
	Mary	C.catfish, fillet	0.04
		R.trout, whole	0.49
		"	0.08
		R.trout, fillet	6 at < 0.01
		"	2 at 0.25
		"	0.23
		"	0.16
		"	2 at 0.22
	Toxic Yard	Bl.bullhead, fillet	0.04
		L.bass, fillet	0.04
1978	Mary	R.trout, fillet	6 BDL
		"	0.05
		"	2 at 0.02
		"	4 at 0.03
		"	0.11
	South Lakes	macrophyte, tops	3 BDL
		macrophyte, roots	2 BDL
		"	0.050
		leeches/snails	BDL
		"	1.41
		Bl.bullhead, whole	0.170
		"	0.080
		L.bass, whole	BDL
		frogs/toads	3 BDL
		"	2 at 0.020
		heron, except feathers and skin	1.540
		"	0.290
		"	0.770

Table B-7 Endrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1979	Lower Derby	Bl.bullhead, fillet	BDL
		"	2 at 0.03
		"	2 at 0.05
		"	0.04
		L.bass, fillet	4 BDL
		"	0.03
		"	0.02
		N.pike, fillet	4 BDL
		"	0.50
		"	0.40
	Ladora	Bl.bullhead, fillet	4 BDL
		"	2 at 0.03
		L.bass, fillet	6 BDL
		N.pike, fillet	5 BDL
	Mary	R.trout, fillet	13 BDL
1980	Lower Derby	Bl.bullhead, fillet	8 BDL
		"	0.03
		"	0.14
		Bluegill, fillet	0.03
		L.bass, fillet	0.04
		N.pike, fillet	2 BDL
		"	0.04
	Ladora	Bl.bullhead, fillet	2 at 0.03
		Bl. bullhead	8 BDL
	Mary	C.catfish, fillet	2 BDL
		L.bass, fillet	7 BDL
1981	Lower Derby	Bl.bullhead, fillet	4 BDL
		"	3 at 0.04
		"	3 at 0.03
		L.bass, fillet	BDL
		N.pike, fillet	7 BDL
		"	2 at 0.03
	Ladora	Bl.bullhead, fillet	10 BDL
		Bluegill, fillet	4 BDL
		L.bass, fillet	4 BDL
		N.pike, fillet	4 BDL
	Mary	L.bass, fillet	12 BDL
1982	Lower Derby	Bl.bullhead, fillet	9 BDL
		"	0.03
		N.pike, fillet	12 BDL
		"	0.04
	Ladora	Bl.bullhead, fillet	7 BDL
		"	3 at 0.03
		Bluegill, fillet	10 BDL

Table B-7 Endrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Ladora (cont.)	L.bass, fillet	6 BDL
		N.pike, fillet	8 BDL
1983	Lower Derby	N.pike, fillet	4 BDL
		Bl.bullhead, fillet	7 BDL
	Ladora	N.pike, fillet	4 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	14 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	5 BDL
		Bluegill, fillet	1 BDL
		C.catfish, fillet	1 BDL
1984	Lower Derby	N.pike, fillet	11 BDL
		L.bass, fillet	7 BDL
		Bluegill, fillet	5 BDL
		Bl.bullhead, fillet	12 BDL
	Ladora	N.pike, fillet	11 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	9 BDL 5 at 0.02 0.03
		Bl.bullhead, fillet	5 BDL 4 at 0.02 0.03
	Mary	L.bass, fillet	20 BDL
		Bluegill, fillet	5 BDL 4 at 0.02 0.03
		C.catfish, fillet	8 BDL 0.02 0.04

1 data sources: McBride (1978); Shell (1964a,c,e); Spectran (1970): Thorne (1982, 1986); Thorne et al. (1979); USA (1977e, 1981b, 1981d).

2 single entries may represent composites of variable or unknown size.

Table B-8 Isodrin concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1964	Upper Derby	sediment	7.9
		"	8.3
		"	4.6
		"	3 at < 1.0
	Lower Derby	sediment	5 at < 1.0
		"	± 1.0
1978	Mary	R.trout, fillet	14 BDL
	South Lakes	macrophyte, tops	2 BDL
		"	0.020
		macrophyte, roots	3 BDL
		leeches/snails	BDL
		"	0.84
		Bl.bullhead, whole	2 BDL
		L.bass, whole	2 BDL
		frogs/toads, whole	4 BDL
		"	0.04
		heron, except feathers and skin	2 BDL
		"	0.09
1979	Lower Derby	N.pike, fillet	6 BDL
		L.bass, fillet	6 BDL
		Bl.bullhead, fillet	6 BDL
	Ladora	N.pike, fillet	6 BDL
		L.bass, fillet	6 BDL
		Bl.bullhead, fillet	6 BDL
	Mary	R.trout, fillet	13 BDL
1980	Lower Derby	Bl.bullhead, fillet	8 BDL
		"	0.03
		"	0.02
		Bluegill, fillet	BDL
		L.bass, fillet	2 BDL
		N.pike, fillet	3 BDL
	Ladora	Bl.bullhead, fillet	10 BDL
		Bluegill, fillet	4 BDL
		L.bass, fillet	4 BDL
	Mary	C.catfish, fillet	2 BDL
		L.bass, fillet	6 BDL
		"	0.03
1981	Lower Derby	Bl.bullhead, fillet	10 BDL
		L.bass, fillet	BDL
		N.pike, fillet	9 BDL
	Ladora	Bl.bullhead, fillet	8 BDL
		"	0.04

Table B-8 Isodrin concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1981	Ladora (cont.)	Bl.bullhead, fillet	0.06
		Bluegill, fillet	2 BDL
		"	0.05
		"	0.19
		L.bass, fillet	4 BDL
		N.pike, fillet	4 BDL
	Mary	L.bass, fillet	12 BDL
1982	Lower Derby	N.pike, fillet	12 BDL
		L.bass, fillet	1 BDL
		Bl.bullhead, fillet	10 BDL
	Ladora	N.pike, fillet	8 BDL
		L.bass, fillet	6 BDL
		Bluegill, fillet	10 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	20 BDL
		C.catfish, fillet	1 BDL
1983	Lower Derby	N.pike, fillet	4 BDL
		Bl.bullhead, fillet	7 BDL
	Ladora	N.pike, fillet	4 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	14 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	5 BDL
		Bluegill, fillet	1 BDL
		C.catfish, fillet	1 BDL
1984	Lower Derby	N.pike, fillet	11 BDL
		L.bass, fillet	7 BDL
		Bluegill, fillet	5 BDL
		Bl.bullhead, fillet	12 BDL
	Ladora	N.pike, fillet	11 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	15 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	20 BDL
		Bluegill, fillet	10 BDL
		C.catfish, fillet	10 BDL

[1] data sources: Thorne et al. (1979, 1986). USA (1977e. 1981d).
[2] single entries may represent composites of variable or unknown size.

Table B-9 DDT concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1963	South Lakes	snails	2 at < 0.01
		leeches	0.7
	Ladora	macrophytes	3 at < 0.01
		terrestrial veg.	1.0
1964	Lower Derby	snails, except shells	0.7
		snails, shells only	< 0.05
	Ladora	snails, except shells	0.5
		snails, shells only	< 0.5
		tadpoles	< 0.5
	Mary	Y.perch, fillet	< 0.05
		"	0.51
		Y.perch, viscera	3.6
1970	Ladora	Bluegill, whole	0.01
		L.bass, whole	0.02
	Mary	Bl.bullhead, whole	0.11
1977	Lower Derby	Bl.bullhead, fillet	0.03
		L.bass, fillet	BDL
	Ladora	Bl.bullhead, fillet	BDL
		L.bass, fillet	BDL
	Toxic Yard	Bl.bullhead, fillet	0.02
		L.bass, fillet	0.02
	Mary	C.catfish, fillet	BDL
1978	Mary	R.trout, fillet	8 BDL
		"	0.40
		"	4 at 0.03
		"	0.04
	South Lakes	macrophyte, tops	2 BDL
		"	0.020
		macrophyte, roots	2 BDL
		"	0.020
		leeches/snails	2 BDL
		Bl.bullhead, whole	BDL
		"	0.03
		L.bass, whole	2 BDL
		frogs/toads	3 BDL
		"	0.04
		"	0.02
		heron, except feathers and skin	1.54
		"	0.20
		"	0.70
	Lower Derby	L.bass	0.12
		Bl.bullhead	0.11

Table B-9 DDT concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1978	Ladora	L.bass	0.15
		Bl.bullhead	0.10
1979	Lower Derby	Bl.bullhead, fillet	3 BDL
		"	0.04
		"	0.06
		"	0.05
		L.bass, fillet	6 BDL
		N.pike, fillet	4 BDL
		"	2 at 0.03
	Ladora	Bl.bullhead, fillet	5 BDL
		"	0.03
		L.bass, fillet	6 BDL
		N.pike, fillet	3 BDL
		"	2 at 0.03
	Mary	R.trout, fillet	13 BDL
1980	Lower Derby	Bl.bullhead, fillet	7 BDL
		"	0.02
		"	0.03
		"	0.04
		Bluegill, fillet	BDL
		L.bass, fillet	0.07
		N.pike, fillet	3 BDL
	Ladora	Bl.bullhead, fillet	10 BDL
		Bluegill, fillet	4 BDL
		L.bass, fillet	4 BDL
	Mary	C.catfish, fillet	2 BDL
		L.bass, fillet	7 BDL
1982	Lower Derby	Bl.bullhead, fillet	10 BDL
		L.bass, fillet	0.10
		N.pike, fillet	8 BDL
		"	2 at 0.04
		"	0.05
		"	0.09
	Ladora	sediment, 0.0-1.0 ft	3 at < 0.0002
		sediment, 1.0-2.0 ft	2 at < 0.0002
		"	0.003
		sediment, 2.0-3.0 ft	3 at < 0.2 ug/kg
		Bl.bullhead, fillet	3 BDL
		"	2 at 0.03
		"	2 at 0.06
		"	0.07
		"	0.04
		"	0.08
		Bluegill, fillet	10 BDL

Table B-9 DDT concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Ladora (cont.)	L.bass, fillet	12 BDL
		"	0.03
		"	0.09
	Mary	sediment, 0.0-1.0 ft	0.002
		"	< 0.0002
		sediment, 1.0-2.0 ft	2 at < 0.0002
		sediment, 2.0-3.0 ft	2 at < 0.0002
		C.catfish, fillet	BDL
		L.bass, fillet	20 BDL
1983	Lower Derby	N.pike, fillet	0.04
			0.05
			0.06
			0.09
		Bl.bullhead, fillet	6 BDL
			0.04
		N.pike, fillet	BDL
			2 at 0.03
			0.09
		L.bass, fillet	5 BDL
		Bluegill, fillet	10 BDL
	Ladora	Bluegill, fillet	3 BDL
			0.03
		Bl.bullhead, fillet	8 BDL
			2 at 0.04
	Mary	L.bass, fillet	5 BDL
		Bluegill, fillet	BDL
		C.catfish, fillet	BDL
1984	Lower Derby	N.pike, fillet	10 BDL
			0.02
		L.bass, fillet	4 BDL
			2 at 0.03
			0.04
		Bluegill, fillet	2 BDL
			2 at 0.02
			0.03
		Bl.bullhead, fillet	6 BDL
			5 at 0.02
			0.03
	Ladora	N.pike, fillet	3 BDL
			3 at 0.02
			2 at 0.03
			0.06
			2 at 0.07
			0.16

Table B-9 DDT concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1984	Ladora (cont.)	L.bass, fillet	4 BDL 0.03
		Bluegill, fillet	8 BDL 4 at 0.03 0.06 0.08 0.50
		Bl.bullhead, fillet	BDL 2 at 0.04 2 at 0.05 0.06 0.08 0.10 0.12
	Mary	L.bass, fillet	17 BDL 0.04 2 at 0.05
		Bluegill, fillet	6 at BDL 0.02 3 at 0.04
		C.catfish, fillet	7 BDL 2 at 0.02 0.05

1 data sources: McBride (1978); Mullan (1975d); Sheldon (1963); Shell (1964 a,e); Spectran Laboratories (1970); Thorne (1982c, 1986); Thorne et al. (1979); USA (1983d).

2 single entries may represent composites of variable or unknown size.

Table B-10 DDE concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1962	South Lakes	tiger salamander	0.1
1964	Lower Derby	snails, except shells	< 0.1
		snails, shells only	< 0.05
	Ladora	snails, except shells	< 0.05
		snails, shells only	< 0.05
		tadpoles	< 0.05
	Mary	water	.0003
		soil	0.16
		Y.perch, fillet	0.23
		Y.perch, viscera	0.75
1970	Ladora	Bluegill, whole	0.1
		L.bass, fillet	0.2
		"	0.3
		L.bass, nonedible	1.6
		"	2.0
		L.bass, whole	0.3
	Mary	Bl.bullhead, whole	0.43
1971	Ladora	Bluegill, fillet	0.50
		L.bass, fillet	0.35
		"	0.70
1977	Lower Derby	Bl.bullhead, whole	0.11
		L.bass, whole	0.12
	Ladora	Bl.bullhead, whole	0.10
		L.bass, whole	0.15
	Mary	R.trout, whole	0.19
		"	0.22
		R.trout, fillet	3 at 0.19
		"	0.22
		"	0.11
		"	0.07
		"	0.15
		"	0.23
		"	0.16
		"	0.12
		"	0.13
		"	0.10
	Mary	Food pellets	0.14
	Toxic Yard	Bl.bullhead	0.03
1978	Mary	R.trout, fillet	0.03
		"	0.02
		"	2 at 0.05
		"	0.25

Table B-10 DDE concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1978	Mary (cont.)	R.trout, fillet	3 at 0.08
		"	2 at 0.07
		"	0.38
		"	0.04
		"	0.09
		"	0.06
	South Lakes	macrophyte, tops	3 BDL
		macrophyte, roots	2 BDL
		"	0.02
		leeches/snails	2 BDL
		Bl.bullhead, whole	0.11
		"	0.10
		L.bass, whole	0.15
		"	0.12
		frogs/toads, whole	4 BDL
		"	0.02
		heron, except feathers and skin	2.91
		"	1.43
		"	0.52
1979	Lower Derby	Bl.bullhead, fillet	BDL
		"	0.04
		"	0.10
		"	0.08
		"	0.07
		"	0.05
		L.bass, fillet	6 BDL
		N.pike, fillet	BDL
		"	2 at 0.03
		"	0.06
		"	0.04
	Ladora	Bl.bullhead, fillet	2 BDL
		"	2 at 0.10
		"	0.09
		"	0.06
		L.bass, fillet	6 BDL
		N.pike, fillet	BDL
		"	0.10
		"	0.11
		"	0.15
		"	0.13
	Mary	R.trout, fillet	BDL
		"	5 at 0.05
		"	0.06
		"	2 at 0.04
		"	0.17

Table B-10 DDE concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1979	Mary (cont.)	R. trout, fillet	0.08
		"	0.02
		"	0.07
1980	Lower Derby	Bl.bullhead, fillet	5 BDL
		"	2 at 0.05
		"	0.10
		"	0.11
		"	0.12
		Bluegill, fillet	0.37
		L.bass, fillet	BDL
		N.pike, fillet	3 BDL
	Ladora	Bl.bullhead, fillet	10 BDL
		Bluegill, fillet	4 BDL
		L.bass, fillet	4 BDL
	Mary	C.catfish, fillet	2 BDL
		L.bass, fillet	7 BDL
		"	0.06
1981	Lower Derby	Bl.bullhead, fillet	7 BDL
		"	0.03
		"	2 at 0.06
		L.bass, fillet	0.05
		N.pike, fillet	2 BDL
		"	6 at 0.03
		"	0.07
	Ladora	Bl.bullhead, fillet	7 BDL
		"	0.03
		"	0.05
		"	0.04
		Bluegill, fillet	4 BDL
		L.bass, fillet	4 BDL
		N.pike, fillet	3 at 0.03
		"	0.04
	Mary	L.bass, fillet	12 BDL
1982	Lower Derby	Bl.bullhead, fillet	3 BDL
		"	2 at 0.06
		"	0.11
		"	0.09
		"	0.05
		"	0.04
		"	0.03
		L.bass, fillet	0.08
		N.pike, fillet	BDL
		"	2 at 0.06
		"	3 at 0.05

Table B-10 DDE concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Lower Derby (cont.)	N.pike, fillet	0.14
		"	0.07
		"	0.20
		"	0.08
		"	0.09
		"	0.03
	Ladora	Bl.bullhead, fillet	5 BDL
		"	0.04
		"	2 at 0.05
		"	0.09
		"	0.07
		Bluegill, fillet	BDL
		"	2 at 0.03
		L.bass, fillet	3 BDL
		"	3 at 0.03
		N.pike, fillet	2 BDL
		"	0.08
		"	3 at 0.03
		"	0.07
		"	0.05
	Mary	C.catfish	0.05
		L.bass, fillet	19 BDL
		"	0.03
1983	Lower Derby	N.pike, fillet	0.03
			0.05
			0.08
			0.21
		Bl.bullhead, fillet	6 BDL
			0.03
	Ladora	N.pike, fillet	0.03
			2 at 0.05
			0.14
		L.bass, fillet	5 BDL
		Bluegill, fillet	13 BDL
			0.03
		Bl.bullhead, fillet	3 BDL
			3 at 0.03
			0.04
			0.05
			0.08
			0.09
	Mary	L.bass, fillet	5 BDL
		Bluegill, fillet	BDL
		C.catfish, fillet	0.09

Table B-10 DDE concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1984	Lower Derby	N.pike, fillet	7 at 0.03
			2 at 0.04
			0.05
			0.06
		L.bass, fillet	0.02
			0.05
			0.09
			0.11
			0.12
			0.13
			0.14
		Bluegill, fillet	2 BDL
			2 at 0.02
			0.03
		Bl.bullhead, fillet	8 BDL
			2 at 0.02
			2 at 0.04
	Ladora	N.pike, fillet	3 BDL
			2 at 0.02
			3 at 0.03
			0.07
			0.08
			0.09
			0.28
		L.bass, fillet	BDL
			3 at 0.02
			0.03
		Bluegill, fillet	5 BDL
			8 at 0.02
			2 at 0.03
		Bl.bullhead, fillet	2 BDL
			5 at 0.02
			0.03
			0.05
			0.06
	Mary	L.bass, fillet	15 BDL
			4 at 0.02
			0.03
		Bluegill, fillet	6 BDL
			0.02
			2 at 0.03
			0.12

Table B-10 DDE concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1984	Mary (cont.)	C.catfish, fillet	2 BDL 3 at 0.04 0.05 3 at 0.06 0.07

[1] data sources: Dean (1971); McBride (1978); Mullan (1975d); Sheldon and Mohn (1962); Shell (1964 a,e); Spectran Laboratories (1970); Thorne (1982c, 1986); Thorne et al. (1979); USA (1977c,d,e); USFWS (1961).

[2] single entries may represent composites of variable or unknown size.

Table B-11 DDD concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1970	Ladora	Bluegill, whole	0.10
		L.bass, whole	0.03
	Mary	Bl.bullhead, whole	0.14

[1] data sources: Mullen (1975d); Spectran Laboratories (1970).
[2] single entries may represent composites of five fish.

Table B-12 Chlordane concentrations[1].

Date	Location	Material Tested	Concentration (ppm)
1964	Mary	solids filtered from water	22.0

[1] data source: USFWS (1961).

Table B-13 Lindane concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1964	Lower Derby	snails, except shells	< 0.03
		snails, shells only	< 0.03
	Ladora	snails, except shells	< 0.03
		snails, shells only	< 0.03
		tadpoles	< 0.03
	Mary	Y.perch, fillet	< 0.01
		Y.perch, viscera	< 0.02
1977	Mary	water	0.00013
	Ladora	water	0.00015
	Lower Derby	water	0.00039

[1] data sources: Shell (1964a,e), USA (1977f).
[2] single entries may represent composites of variable or unknown size.

Table B-14 Nemagon concentrations[1].

Date	Location	Material Tested	Concentration (ppm)
1978	Mary	R.trout, fillet	5 BDL
		"	3 at 0.04
		"	0.02
		"	0.12
		"	0.09
		"	0.55
		"	0.03
		"	0.05

[1] data source: Thorne (1982c).

Table B-15 Heptachlor epoxide concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1964	Lower Derby	snails, except shells	< 0.05
		snails, shells only	< 0.05
	Ladora	snails, except shells	< 0.05
		snails, shells only	< 0.05
		tadpoles	< 0.05
	Mary	Y.perch, fillet	< 0.02
		Y.perch, viscera	< 0.03
		R.trout, fillets	12 at < 0.01
		R.trout, whole	0.03

[1] data sources: Shell (1964e); USA (1977c,d,e).
[2] single entries may represent composites of variable or unknown size.

Table B-16 Methylene chloride concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Ladora	water	0.018
		"	0.010
		sediment, 0.0-1.0 ft	0.057
		"	< 0.025
		"	0.068
		sediment, 1.0-2.0 ft	0.012
		"	0.042
		"	0.043
		sediment, 2.0-3.0 ft	0.013
		"	0.068
		"	0.091
	Mary	sediment, 0.0-1.0 ft	< 0.025
		"	0.047
		sediment, 1.0-2.0 ft	2 at < 0.025
		sediment, 2.0-3.0 ft	2 at < 0.025
		water	0.033

[1] data source: USA (1983d).
[2] single entries may represent composites of variable or unknown size.

Table B-17 PCB concentrations[1].

Date	Location	Material Tested	Concentration[2] (ppm)	
1977	Mary	R.trout, fillet	0.11	16.4
		"	0.09	8.3
		"	0.28	23.2
		"	0.16	11.3
		"	0.24	17.1
		"	0.04	25.0
		"	0.21	12.4
		"	0.21	23.3
		"	0.02	10.0

[1] data source: USA (1977f).
[2] 1st column = fresh weight basis; second = lipid weight basis.

Table B-18 DIMP concentrations[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1977	Lower Derby	Bl.bullhead, fillet	0.06
		L.bass, fillet	0.06
	Ladora	Bl.bullhead, fillet	2 at 0.09
	Toxic Yard	Bl.bullhead, fillet	BDL
		L.bass, fillet	BDL
	Mary	C.catfish, fillet	BDL
1978	Mary	R.trout, fillet	13 BDL
		"	0.17
	South Lakes	macrophyte, tops	3 BDL
		macrophyte, roots	3 BDL
	North Bog	macrophyte, tops	0.37
1979	Lower Derby	N.pike, fillet	6 BDL
		L.bass, fillet	6 BDL
		Bl.bullhead, fillet	6 BDL
	Ladora	N.pike, fillet	6 BDL
		L.bass, fillet	6 BDL
		Bl.bullhead, fillet	6 BDL
	Mary	R.trout, fillet	13 BDL
1980	Lower Derby	N.pike, fillet	3 BDL
		L.bass, fillet	1 BDL
		Bluegill, fillet	1 BDL
		Bl.bullhead, fillet	10 BDL
	Ladora	L.bass, fillet	4 BDL
		Bluegill, fillet	4 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	7 BDL
		C.catfish, fillet	2 BDL
1981	Lower Derby	N.pike, fillet	9 BDL
		L.bass, fillet	1 BDL
		Bl.bullhead, fillet	10 BDL
	Ladora	N.pike, fillet	4 BDL
		L.bass, fillet	4 BDL
		Bluegill, fillet	4 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	12 BDL
1982	Lower Derby	N.pike, fillet	12 BDL
		L.bass, fillet	1 BDL
		Bl.bullhead, fillet	10 BDL
	Ladora	N.pike, fillet	8 BDL
		L.bass, fillet	6 BDL
		Bluegill, fillet	10 BDL
		Bl.bullhead, fillet	10 BDL

Table B-18 DIMP concentrations (continued)[1].

Date	Location	Material Tested[2]	Concentration (ppm)
1982	Mary	L.bass, fillet	20 BDL
		C.catfish, fillet	1 BDL
1983	Lower Derby	N.pike, fillet	4 BDL
		Bl.bullhead, fillet	7 BDL
	Ladora	N.pike, fillet	4 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	14 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	5 BDL
		Bluegill, fillet	1 BDL
		C.catfish, fillet	1 BDL
1984	Lower Derby	N.pike, fillet	11 BDL
		L.bass, fillet	7 BDL
		Bluegill, fillet	5 BDL
		Bl.bullhead, fillet	12 BDL
	Ladora	N.pike, fillet	11 BDL
		L.bass, fillet	5 BDL
		Bluegill, fillet	15 BDL
		Bl.bullhead, fillet	10 BDL
	Mary	L.bass, fillet	20 BDL
		Bluegill, fillet	10 BDL
		C.catfish, fillet	10 BDL

[1] data sources: Thorne (1982c, 1986); Thorne et al. (1979).
[2] single entries may represent composites of variable or unknown size.

Table B-19 bis (2-ethylhexy) phthalate concentrations[1].

Date	Location	Material Tested	Concentration (ppm)
1982	Ladora	sediment, 0.0-1.0 ft	< 0.2
		"	0.21
		"	< 0.02
		sediment, 1.0-2.0 ft	0.2
		"	< 0.2
		"	< 0.025
		sediment, 2.0-3.0 ft	0.55
		"	0.48
		"	0.2
	Mary	sediment, 0.0-1.0 ft	< 0.2
		"	0.41
		sediment, 1.0-2.0 ft	0.74
		"	< 0.2
		sediment, 2.0-3.0 ft	0.22
		"	< 0.2

[1] data source: USA (1983d).