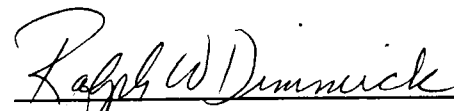


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RADIOACTIVE AND NON-RADIOACTIVE CONTAMINANTS IN MIGRATORY
AND RESIDENT WATERFOWL INHABITING THE OAK RIDGE
RESERVATION, EAST TENNESSEE

A Thesis
Presented for the
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Alicia E. Waters

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ABSTRACT

The concentrations of radionuclides and metals accumulated in tissues of waterfowl inhabiting the Oak Ridge Reservation (ORR) were determined in addition to the composition and density of waterfowl species using ORR waste ponds, streams, and lakes. Waterfowl using the ORR may serve as a vector in transporting contamination off the ORR and into the human food chain.

Weekly observations of ORR aquatic areas were made to determine the composition and density of waterfowl species. More than 16,000 observations of waterfowl have been recorded for the designated locations. Both migratory and resident birds inhabit the waste ponds and streams on the ORR, especially during winter. Resident Canada geese (*Branta canadensis*) at the ORR and surrounding areas were fitted with neck-collars to determine their movement patterns. The available data indicated that the collared Canada geese use both the ORR and areas accessible to the public.

Migratory waterfowl and coots (*Fulica americana*) were collected from White Oak Lake (WOL) at the Oak Ridge National Laboratory (ORNL) to determine radionuclide and metal concentrations in their tissues. Resident Canada geese from ORNL were also analyzed for radioactive and non-radioactive contamination. Cesium-137 and ^{90}Sr were the primary radionuclides detected in waterfowl. The maximum ^{137}Cs concentrations in breast tissue from a dabbling species (gadwall, *Anas strepera*) collected from WOL was 340 Bq/kg in comparison to 272 Bq/kg of ^{137}Cs in breast tissue of a WOL wood duck (*Aix sponsa*). The highest

concentrations of ^{137}Cs in breast tissue (146,000 Bq/kg) and ^{90}Sr in bone (40,000 Bq/kg) were detected in a pair of Canada geese nesting on a waste pond within the ORNL enclosure. Detectable levels of mercury, selenium, cadmium, and lead were found in wild waterfowl collected from the ORR. Cadmium concentrations in kidney and selenium concentrations in breast tissue were significantly higher in adults than in immature wood ducks.

Two groups of domestic mallards (*Anas platyrhynchos*) were released on WOL to determine the uptake of ^{137}Cs , ^{90}Sr , and mercury by tissues over time. The contaminant levels increased in tissues with time. The concentrations of radionuclides and metals detected in the tissues of the domestic mallards were comparable to levels in tissues of migratory waterfowl. Therefore, the length of time migratory waterfowl resided on WOL was probably less than 60 to 95 days; the maximum time the domestic mallards resided on WOL.

The maximum effective dose commitment to humans from the consumption of 1600 grams of breast tissue from a Canada goose collected from ORNL's Basin 3524 would be 3.1 mSv. Consumption of 298 grams of breast tissue from a migratory gadwall collected at WOL would only give a potential effective dose commitment of 1.4 μSv . Concentrations of mercury, selenium, cadmium, and lead detected in ORR waterfowl were generally below acceptable levels for ingestion by humans. Elevated levels of silver and lead were detected in tissues from several WOL domestic mallards.

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CHAPTER 1

INTRODUCTION, OBJECTIVES, LITERATURE REVIEW

1.1. INTRODUCTION

Waste effluents from industry and from nuclear and fossil fueled power plants are released into isolated disposal impoundments as well as into streams, ponds, and lakes. In agricultural areas, contaminant-laden run-off from crops treated with pesticides and other chemicals enter aquatic ecosystems that are used extensively by wildlife species. Although waste elimination is regulated, elevated levels of pollutants can accumulate in public waterways. These pollutants include radionuclides and metals. Not only do contaminants accumulate in the sediment, soil, and water, but they are also taken up by wildlife and other biota. Many studies have shown that wildlife species inhabit contaminated areas and accumulate pollutants in their tissues (Willard 1960; Reichle et al. 1970; Straney et al. 1975; Domby et al. 1977; Millard et al. 1978a; Halford et al. 1978a, 1981, 1983; DiGiulio and Scanlon 1984b; White and Cromartie 1985). Concentrations of some contaminants found in the environment are above safe levels for biota (Vermeer et al. 1973, Fimreite 1974, Ohlendorf et al. 1986).

Wildlife residing in a contaminated habitat are potential vectors for transporting pollutants outside a contaminated area. Waterfowl and other game bird species are of special concern because they are highly mobile, have species-specific behaviors, and are consumed by humans. Heavy metals can be retained for extensive periods in body tissues and are readily available to a person who consumes a contaminated bird. Although most

radionuclides are generally excreted quickly from the body, a bird harvested immediately after leaving a contaminated area could pose a health hazard to humans (Fendley et al. 1977, Halford et al. 1983, Hutchinson and Meema 1987).

The United States Department of Energy (DOE) Oak Ridge Reservation (ORR) in east Tennessee is a good example of an environment contaminated from industrial processes. Most of the contaminants in ORR aquatic and terrestrial systems have been documented. Although investigators have measured levels of radionuclides and metals in fish and other biota, little research has been conducted on the contaminants in waterfowl that use the ORR (Loar et al. 1981a, Loar 1987, Oakes et al. 1987). Many of the waste ponds at the ORR are attractive to aquatic birds, especially White Oak Lake (WOL) at Oak Ridge National Laboratory (ORNL). Waterfowl have used this wetland area since it was created in 1943 (Krumholtz 1954).

East Tennessee is located in the Mississippi Flyway. Waterfowl habitat in east Tennessee is used primarily for staging and wintering areas for most species. Wood ducks (*Aix sponsa*) and Canada geese (*Branta canadensis*) are the primary species breeding in this area (J. Evans, TWRA, personal communication).

Although migratory Canada geese have always used areas in east Tennessee, resident populations of Canada geese are not native. The Tennessee Valley Authority (TVA) and the Tennessee Wildlife Resources Agency (TWRA) first introduced resident geese to the Melton Hill region, Tennessee in 1972 (J. Evans, TWRA, personal communication). Since their introduction, the resident goose population has increased significantly. As a result of the growing numbers of Canada geese inhabiting east Tennessee,

normally undesirable habitats may be used for roosting and nesting. Geese prefer flat, grassy areas near water with ample vegetation for food (Bellrose 1976). For example, Basin 3524, a former component of the radioactive waste treatment facilities at ORNL which still contains relatively high levels of radioactivity, would not be considered ideal habitat for Canada geese. However, geese have nested in this area during the past several years (Oakes et al. 1987). Furthermore, relatively large flocks of Canada geese occupy ponds and streams located at Y-12 and ORGDP.

Most investigators assume that (1) use of waste areas by waterfowl is low, (2) waterfowl do not stay on ponds long enough to obtain significant contaminant levels, and (3) the probability of a hunter harvesting a contaminated bird and the dose to humans is very low (Brisbin et al. 1973; Halford et al. 1978a, b; Halford et al. 1981). Pollutant residues that accumulate in tissues of ORR waterfowl need to be determined because the ORR borders public waterways and environs which are used for hunting. Waterfowl utilizing ORR waste disposal ponds and settling basins are capable of accumulating contaminants and migrating off the ORR where they may be harvested and consumed by a hunter. The composition and density of the waterfowl species inhabiting the ORR's aquatic ecosystems have not been established, nor have the interactions of ORR waterfowl populations with other local flocks. Furthermore, the movement and migration of birds that use a contaminated area and their interactions with other local flocks is important in considering off-site transfer of radionuclides and other pollutants.

1.2. OBJECTIVES

The objectives of this study were (1) to identify the composition and density of waterfowl species inhabiting the ORR and determine whether these are resident or transient waterfowl populations, (2) to determine the concentrations of radionuclides and metals in tissues of waterfowl using the ORR environs, (3) to determine whether contaminant levels in waterfowl tissues exceed standard limits in foods for consumption by humans, and 4) to determine the movement of ORR Canada geese and their interaction with other local flocks.

1.3. LITERATURE REVIEW

Most industrial wastes are deposited in restricted or isolated sites; however, there is potential for movement of these pollutants to other areas. These contaminants include radionuclides and metals such as cadmium, lead, mercury, and selenium (Brisbin and Swinebroad 1975, White and Cromartie 1985, Eisler 1985a and b, 1986, 1987). Wildlife species often reside in contaminated habitats and therefore are potential vectors for transporting pollutants outside of restricted areas (Brisbin et al. 1973, Dombey et al. 1977, Fendley et al. 1977, Halford et al. 1981, White and Cromartie 1985).

Certain game bird species are of primary concern because they are highly mobile, migratory, and consume a variety of pollutant-concentrating foods ranging from plankton to macrophytes to invertebrates (Konings et al. 1984). Waterfowl are both a recreational and a food source for man; thus,

birds that occupy a contaminated waterway may pose a potential health hazard to humans (Halford and Markham, 1984).

More than twelve million waterfowl reproduce in the United States each year, according to the U.S. Fish and Wildlife Service, and they are an important wildlife resource to the United States, Canada, and Mexico (Tiner 1984). However, wetlands, the primary habitat of waterfowl and other aquatic birds, are rapidly disappearing due to agriculture, urbanization, and industrial development. Wetlands are being destroyed at a rate of 120,000 to 180,000 acres per year, and as a result, waterfowl numbers have been declining (Barton 1987, Chandler 1987). As natural wetlands decline, the birds are more likely to utilize waste disposal areas for feeding, nesting, and roosting areas or as wintering grounds.

This literature review emphasizes those studies investigating environmental contaminants in relation to aquatic birds. The review is divided into 2 sections: (1) radionuclides and (2) metals. The literature shows that waterfowl and other aquatic birds do accumulate environmental contaminants in their tissues under both natural and experimental conditions.

1.3.1. **RADIONUCLIDES**

Studies on radionuclides in relation to wild birds have been conducted primarily at national laboratories. Investigations have focused on radiosensitivity of birds, avian use of contaminated areas, accumulation and elimination of radionuclides, radiation dose to waterfowl, and radiation dose to humans from consuming a contaminated bird.

1.3.1.1. Radiosensitivity

The sensitivity of mallards to gamma radiation was investigated in two separate studies (Curnow et al. 1970, Abraham 1972). An LD₅₀₋₃₀ of 630 R was determined for 108 mallards exposed to ⁶⁰Co at 25 R per minute. All deaths occurred within 17 days post-irradiation (Curnow et al. 1970). Death resulted from hemorrhaging of internal tissues. The LD₅₀₋₃₀ reported by Abraham (1972) was 704 R for mallards exposed to ¹³⁷Cs at 51 R per minute. All deaths occurred within 18 days post-irradiation. Additionally, Tester et al. (1968) examined the radiosensitivity of blue-winged teal (*A. discors*), green-winged teal (*A. crecca*), and shovelers (*A. clypeata*). The LD₅₀₋₃₀ determined from whole-body irradiation with ¹³⁷Cs at 51 R per minute was 485 R for green-winged teal, 715 R for blue-winged teal, and 894 R for shovelers. Birds that died in the first 24 hours post-irradiation showed profuse intestinal hemorrhaging.

Barn swallows (*Hirundo rustica*) naturally occupying radioactive leaching ponds on the Idaho National Engineering Laboratory (INEL) were observed for differences in growth rate and reproduction caused by radiation exposure (Millard et al. 1978a). The swallows accumulated over 20 fission and activation products in their tissues, but the accumulated dose of 219 µGy/d (21.9 mrad/d) for adults was below levels that may affect fertility. The main radionuclide contributors were ²⁴Na, ¹³¹I, and ¹³⁷Cs. However, the first clutch of Test Reactor Area (TRA) immatures showed a lower mean growth rate than did the first clutch of controls. The internal dose rate for immatures was 0.054 mGy (5.4 mrad) per day.

1.3.1.2. Use Of Radioactive-Contaminated Areas

The use of radioactive waste disposal ponds by aquatic birds has been documented in several studies. In the early 1950's, transient waterfowl using WOL, a settling basin at ORNL, included mallard, wood duck, black duck (*A. rubripes*), coot, pintail (*A. acuta*), gadwall, baldpate (*A. americana*), and green-winged teal. Waterfowl were banded to obtain information regarding the birds' movement patterns. These banded birds were later found in Kentucky, Alabama, Louisiana, Texas, Canada, and other parts of Tennessee (Krumholtz 1954) indicating a wide range of movement for migratory waterfowl using WOL. Terrestrial birds also used this lake area (Willard 1960). Furthermore, when the lake was later drained for a short period, investigators observed hundreds of waterfowl using the lake bed (Boyle et al. 1982).

At Battelle Northwest Laboratory (BNWL) in Washington, Fitzner and Price (1973) surveyed the waterfowl on the Hanford waste water ponds. Greatest waterfowl use of waste ponds was observed in the fall, while the lowest numbers were censused from mid-May to mid-August. The lower numbers of birds observed in the summer may result from decreased visibility of nesting birds. Mallard was the most abundant dabbling duck, and ring-necked duck (*Aythya collaris*) was the most numerous diving duck. Coots, mergansers (*Mergus sp.*), and Canada geese were observed occasionally. Mallard, pintail, scaup (*A. affinis*, *A. marila*), redhead (*A. americana*), ruddy duck (*Oxyura jamaicensis*), and coot nested in the area. The primary winter residents were bufflehead (*Bucephala albeola*), goldeneyes (*B. clangula*), ring-necked duck, and gadwall. The suitability of the waste ponds for waterfowl habitat depended on the physical features and food supply of the

ponds. Diving ducks were not attracted to the small and shallow waste ponds (Fitzner and Price 1973).

On the TRA radioactive leaching ponds at INEL, over 3100 waterfowl were censused from 1974 to 1978. Mallards and green-winged teal were the most abundant waterfowl inhabiting the ponds (Halford et al. 1978a, Halford et al. 1981, Halford et al. 1982).

1.3.1.3. Accumulation and Elimination of Radionuclides

The accumulation and elimination of radionuclides in waterfowl has been determined under both natural and experimental conditions. The seasonal uptake of fission products by birds occupying the WOL bed was determined by Willard (1960). The birds accumulated ^{90}Sr and ^{137}Cs in the summer, primarily through the food chain; however, in the winter, ingestion of contaminated soil accounted for uptake of radionuclides.

At the Savannah River Plant, a national laboratory in South Carolina, Brisbin et al. (1973) monitored monthly coot whole-body burdens from a natural population on a reactor cooling pond. From October 1971 to May 1972, approximately 30 coots per month were shot and analyzed for radioactivity. The coots averaged 148 to 296 Bq/kg (4 to 8 pCi/g) (fresh weight) of radiocesium in October, and their body burdens rose approximately 74 to 111 Bq/kg (2 to 3 pCi/g) per bird per month to a maximum of 555 to 740 Bq/kg (15 to 20 pCi/g) in January and February. By May, the coot body burdens returned to levels similar to those in the previous fall. Brisbin et al. (1973) explained this rise in radiocesium concentrations by the coot migration to the pond for winter. Radionuclide concentrations built up in coot tissues the

longer these same birds remained on the pond. However, in late spring, as new coots arrived from uncontaminated areas for breeding, the average whole-body burdens of the coot population began to decrease.

The radiocesium body burden in herons on a contaminated reservoir at the Savannah River Plant has been related to variation in food sources (Domby et al. 1977). Little blue herons (*Florida caerulea*) that obtained their food from a contaminated pond showed significant radiocesium concentrations in comparison to green-backed herons (*Butorides striatus*) nesting in the same area. The green herons obtained their food from adjacent uncontaminated areas. Variations of radiocesium concentrations were also observed among juveniles from different nests. Between 45 and 71 percent of this variability in nestling body burdens could be explained by their food variability (Domby et al. 1977). Conversely, Straney et al. (1975) reported that juvenile uptake rates for terrestrial bird species from six locations at the Savannah River Plant were proportional to weight and age rather than diet or location. Differences in the radiocesium body burdens of adult birds, however, were due to the diets of birds at each location.

Wood ducks released into an enclosure in a swamp contaminated with reactor effluents at the Savannah River Plant attained practical equilibrium for ^{137}Cs in live whole body in 17.3 days, with a range of 10.2 to 26.8 days (Fendley et al. 1977). Mallards released on a liquid radioactive waste pond at INEL were also studied for biological accumulation and elimination. The time needed for the mallards to attain practical equilibrium in whole body for ^{137}Cs averaged 37 days, with a range of 23 to 56 days (Halford et al. 1983). In both experiments, ducks fed on food available in the contaminated aquatic ecosystems. Fendley et al. (1977) indicated that naturally contaminated

animals in or near radionuclide equilibrium with their contaminated environment would show a single-component elimination-rate curve under penned conditions. This single-phased elimination curve would result because naturally contaminated organisms at equilibrium with contaminant levels in their foods often contain only a small proportion of their total body burden in their gut contents. The mallards in Halford 's et al. (1983) study exhibited a two-component elimination for most radionuclides detected. Furthermore, Halford et al. (1983) determined that the biological half-lives for detected radionuclides were 11 days (^{137}Cs), 10 days (^{134}Cs), 10 days (^{131}I), 26 days (^{75}Se), 67 days (^{65}Zn), 67 days (^{60}Co), and 86 days (^{51}Cr). These biological half-lives correspond with previously determined values recorded by Halford et al. (1978b). The ^{137}Cs biological half-time for wood ducks averaged 5.6 days, with a range of 3.2 to 9.3 days (Fendley et al. 1977).

Wild ducks collected from radioactive leaching ponds at INEL contained up to 29 radionuclides. Halford et al. (1983) reported that mallard gut samples retained the highest radionuclide concentrations, followed by feather, liver, and muscle. This trend is similar to a mallard study by Halford et al. (1978b) in which feathers accumulated the highest concentrations, followed by gut, liver, and muscle. Chromium-51 had the highest concentrations of all radionuclides in the gut (4.81 MBq or 130,000 pCi/g fresh wt.). The highest levels of ^{137}Cs were in muscle samples (0.15 MBq/kg or 4070 pCi/g fresh wt.) (Halford et al. 1978a, Halford et al. 1981). Cesium-134 and ^{137}Cs were detected in 82% and 91% of muscle samples, respectively, and these radionuclides would contribute 98% of the potential dose to humans (Halford et al. 1982). Liver tissues concentrated high levels of ^{110m}Ag , ^{75}Se , ^{65}Zn , ^{134}Cs , ^{137}Cs , ^{144}Ce , and ^{60}Co in comparison to

other tissues (Halford et al. 1981). Edible tissues contained lower radionuclide levels than non-edible tissues (Halford et al. 1978a, Millard et al. 1978b, Halford et al. 1981). Halford et al. (1981) found no significant difference in ^{137}Cs levels between dabbling ducks and diving ducks.

In waterfowl collected in the late 1940's from the Columbia River, which flows through BNWL reservation, ^{32}P was the most commonly detected isotope in waterfowl tissues, but ^{131}I was found in the highest concentrations (Herde and Cline 1949, Herde et al. 1951). Additionally, biotic and abiotic components of Gable Mountain Pond, the largest waste water pond on the BNWL reservation, were studied to determine if the potential for off-site transfer of radioactivity by waterfowl exists. Mallards restricted to the pond contained a mean concentration of 0.011 MBq/kg (290 pCi/g) (dry wt.) of ^{137}Cs in muscle tissue. Resident coots contained a mean ^{137}Cs concentration of 0.018 MBq/kg (480 pCi/g) (dry wt.) in muscle tissue. The ^{137}Cs concentration in wild transient duck tissues was much lower, 2294 Bq/kg (62 pCi/g) (dry wt.) (Cushing and Watson 1974).

To determine whether waterfowl might transport radionuclides off-site from the ORR, four Canada geese that resided near Basin 3524 at ORNL were collected to determine radionuclide uptake (Oakes et al. 1987). Analyses for radionuclides in crop, bone, and muscle tissue indicated a high uptake of ^{137}Cs and ^{90}Sr , but a rapid elimination of ingested ^{60}Co , ^{137}Cs , ^{152}Eu , and ^{154}Eu in fecal material. Average ^{90}Sr concentrations in muscle and bone were 67 Bq/kg (1.8 pCi/g) (fresh wt.) and 0.028 MBq/kg (750 pCi/g) (fresh wt.), respectively. Muscle concentrations for ^{137}Cs ranged from 0.052 MBq/kg to 0.137 MBq/kg (1400 to 3700 pCi/g) (fresh wt.) and for ^{60}Co from 340 to 592 Bq/kg (9.2 to 16 pCi/g) (fresh wt.). Liver concentrations for ^{137}Cs

ranged from 0.040 to 0.065 MBq/kg (1100 to 1750 pCi/g) (fresh wt) and 703 to 2070 Bq/kg (19 to 56 pCi/g) (fresh wt.) for ^{60}Co . Because of the small size of Basin 3524, the probability of many geese using this basin is small (Oakes et al. 1987). However, as the geese population increases at ORNL, more birds may attempt to nest on small and contaminated waste ponds at the ORR, such as Basins 3524 and 3513.

Waterfowl eliminate radionuclides from the body fairly rapidly. After confinement in a cage for 51 days, waterfowl contained the highest levels of radionuclides in their feathers, followed by liver, muscle, and gut. Elimination was most rapid in the gut (Halford et al. 1983). After a bird leaves a contaminated area, the levels of radionuclides in feces decrease significantly during the first 10 days and then level out over time (Fendley et al. 1977, Halford et al. 1983). If a contaminated waterfowl were to be consumed one month after leaving a pond, the internal dose from ^{134}Cs and ^{137}Cs to humans would be reduced by at least 80 percent (Halford et al. 1983).

1.3.1.4. Radiation Dose to Waterfowl

Radiation dose to waterfowl results from both internally and externally deposited radionuclides. Only 10 percent of gamma radiation from an internal emitter is absorbed by duck tissues. In comparison to gamma radiation, all beta radiation is absorbed. If wild ducks resided on the TRA ponds at INEL for approximately 6 days, they would accumulate a total dose of 11.8 mGy (1180 mrad) from external and internal deposited gamma radionuclides (Halford et al. 1982). Total whole-body dose from ^{129}I to muscle tissue in waterfowl would be 3.0×10^{-7} mGy (3.0×10^{-5} mrad) from the TRA ponds (Halford and

Markham 1984). The maximum dose that could be accumulated by an American coot that spends 20 days on a TRA pond would be 0.056 Gy (5.6 rad) (Halford et al. 1982). Markham et al. (1988) reported that ducks used in an experiment on the radioactive leaching ponds at INEL received a total dose rate of 0.69 mGy d⁻¹ (69 mrad d⁻¹) from ⁹⁰Sr and transuranic radionuclides (²³⁸Pu, ^{239,240}Pu, ²⁴¹Am, ²⁴²Cm, and ²⁴⁴Cm).

Internal radiation dose variability in waterfowl seems to depend most on the time the bird spends on a contaminated pond and the differences in food habits and metabolism among birds. If radionuclide concentrations vary in each ecosystem component of a pond, the individual ducks would consume varying concentrations of radionuclides depending on the ecosystem component exploited for food. Doses to birds from external radiation sources were less variable than doses from internal radionuclides (Halford et al. 1982).

1.3.1.5. Export of Radionuclides by Waterfowl

Waterfowl export radioactivity off-site of contaminated areas. According to Millard et al. (1978b), birds export radioactivity from TRA ponds at INEL at a rate of 5.0×10^7 Bq/y (1350 μ Ci/y). Halford et al. (1981) reported approximately the same export rate. Wild ducks using radioactive leaching ponds at INEL would export 11.3 kBq (305 nCi) of transuranics in one year (Markham et al. 1988). Furthermore, migratory waterfowl may remove up to 1.39×10^6 Bq (3.75×10^{-5} Ci) of radiocesium per year from the Savannah River Plant reservoir and redistribute it elsewhere (Brisbin et al. 1973).

1.3.1.6. Potential Radiation Dose to Humans

Concentrations of radionuclides detected in waterfowl is used to calculate the potential radiation dose to humans. The potential effective dose equivalent to a human consuming the entire muscle and liver of one experimental duck with average transuranic nuclide concentrations reported in Markham et al. (1988) would be 0.46 μ Sv (0.046 mrem). A hunter consuming a duck from the TRA pond would average 0.12 mSv (12 mrem) whole-body dose commitment and 0.07 mSv (7 mrem) thyroid dose commitment for gamma-emitting radionuclides. The highest calculated potential dose commitment based on muscle and liver concentrations of an American coot residing on TRA ponds for 20 days would be 0.54 mSv (54 mrem) whole-body and 0.86 mSv (86 mrem) thyroid (Halford et al. 1978a, Halford et al. 1981). The U.S. DOE's radiation protection standard for occupational exposure limits the whole-body dose to humans to 5 mSv/yr (500 mrem/yr) and the thyroid dose to 15 mSv (1500 mrem/yr). The DOE national laboratories operate at a dose of 1 mSv (100 mrem) to the local population (Gilbert et al. 1985). A hunter would have to consume 40 birds with the average radionuclide concentrations to exceed the permissible whole-body dose (Halford et al. 1981). Since the American coot is not an important food species and retains higher radionuclide concentrations because of its resident nature, a hunter would most likely receive a lower whole-body dose if he consumed another species of contaminated game bird from the TRA ponds. Halford et al. (1978a, 1981, 1983) indicated that the consumption of a contaminated duck from the TRA ponds would pose little radiation hazard to a person. Furthermore, a BNWL study determined that if a

person ingested ten one-half pound meals of duck with ^{137}Cs concentrations of 0.019 MBq/kg (520 pCi/g) (dry wt.) in muscle tissue, the radiation dose would be 0.28 mSv (28 mrem) whole body (Cushing and Watson 1974).

Greylag geese (*Anser anser*) and European wigeon (*Anas penelope*) that graze the saltmarshes in the Ravenglass estuary, UK, contained low ^{137}Cs concentrations in tissues. A person would have to consume 202 geese and 167 wigeons to yield 1 percent of the annual limits on intake of radioactive-contaminated foods (Lowe and Horrill 1986).

Halford (1983) determined that the radionuclide content in the liver and carcass of mallards is significantly reduced after cooking due to volatilization. Cesium-134 and ^{137}Cs decreased 27 percent in the carcass after cooking, and the dose commitment to humans is also reduced by that amount. However, dose calculations from radionuclide concentrations in uncooked tissues are a conservative approximation of the dose received by a person consuming a contaminated waterfowl.

1.3.1.7. Summary

Waterfowl use radioactive-contaminated ponds and accumulate the radionuclides, especially ^{137}Cs , in their tissues. The LD₅₀₋₃₀ for mallards exposed to radiation is 630-704 R. Ducks attain equilibrium with a contaminated environment in approximately one month. Gut and feather samples tend to accumulate radionuclides in the highest concentrations, but muscle tissue especially accumulates ^{137}Cs . Factors affecting radionuclide body burdens in waterfowl vary among species and with diet. Consuming a contaminated duck which inhabited radioactive waste ponds at a national

laboratory would provide only a fraction of current dose limits and would probably not pose a radiation hazard.

1.3.2. METALS

Aquatic birds may be exposed to elevated concentrations of metals directly or through the food chain from occupying contaminated areas (Gasaway and Buss 1972, White and Cromartie 1985). Investigators have addressed this concern by researching the accumulation of metals in bird tissues, the influence of diet on metal accumulation, and the toxicity of metals to aquatic birds (DiGiulio 1982, DiGiulio and Scanlon 1984a, White and Cromartie 1985). Metals often detected in aquatic birds are cadmium, lead, selenium, and mercury (DiGiulio 1982, DiGiulio and Scanlon 1984a, Heinz and Gold 1987, Saiki and Lowe 1987).

Most metals detected in bird tissues are accumulated through the diet. Significant correlations exist among residues in the soil, vegetation, and consumer organism (animal). However, surface contamination of plant material rather than metal incorporated in plant tissue accounts for a majority of the metal in an animal's diet (Sharma and Shupe 1977).

The U.S. Food and Drug Administration (FDA) established safe levels for the protection of human health from ingestion of certain contaminants (e.g., mercury, PCBs, DDT, dieldrin) in edible portions of fish and poultry (Winger et al. 1984). The U.S. Environmental Protection Agency (EPA) provided acceptable daily intake (ADI) levels as a guideline in evaluating levels of exposure to or ingestion of inorganic and organic pollutants (Lappenbusch 1988). However, these levels may not reflect the potential or real

environmental impacts of these contaminants. Residue levels in fillets of fish are generally lower than those in whole-body residues; thus, predators consuming the entire prey are exposed to higher levels of contaminants. The National Academy of Science and National Academy of Engineering (NAS-NAE) have recommended safety limits for the protection of aquatic life (Winger et al. 1984).

1.3.2.1. Cadmium and Lead

Cadmium is a nonessential toxic metal that occurs in the environment naturally and from industries associated with production of lead, zinc, and copper. The highest concentrations of cadmium are most likely in regions of smelters and in urban industrial areas where cadmium is used in electroplating, pigment production, and the manufacture of batteries and plastic stabilizers (Eisler 1985a). A known teratogen, carcinogen, and mutagen, cadmium binds to specific metal-binding proteins in the liver, kidneys, and other organs (Sharma and Shupe 1977). Cadmium residues in vertebrate kidney and livers $<10 \mu\text{g/g}$ fresh wt. is evidence of cadmium contamination (Eisler 1985a). In studies demonstrating toxic effects at high level exposures, cadmium may produce histological changes in kidney, liver, gastrointestinal tract, testes, heart, blood vessels, bone marrow, and pancreas as well as induce testicular hypoplasia and inhibit spermatogenesis in both birds and mammals (White and Finley 1978, Mayack et al. 1981). Humans should not ingest more than 12 to 75 $\mu\text{g/day}$ of cadmium (Eisler 1985a).

Lead is neither an essential nor a beneficial element to health. Lead is mutagenic and teratogenic in excessive amounts and has carcinogenic

properties. Environmental pollution from lead is widespread through anthropogenic activities including the manufacturing of storage batteries, gasoline additives, pigments, alloys, and ammunition. Lead is toxic in most of its chemical forms and can enter the body by ingestion, inhalation, dermal absorption, and placental transfer to the fetus. Being an accumulative metabolic poison that affects behavior, lead can also cause hematopoietic, vascular, nervous, renal, and reproductive abnormalities (Eisler 1988). The level of lead in blood is widely accepted as the laboratory test to measure lead exposure (Mautino and Bell 1987).

1.3.2.1.1. Cadmium and Lead in Waterbirds

White and Finley (1978) and Mayack et al. (1981) showed that high levels of cadmium (100-200 $\mu\text{g/g}$) did not significantly affect body weight of wood ducks or mallards. The kidneys and liver accumulated the highest concentrations of cadmium. At cadmium treatments of 10 $\mu\text{g/g}$, wood ducks concentrated mean liver and kidney tissue residue levels of 27 $\mu\text{g/g}$ and 62 $\mu\text{g/g}$, respectively (Mayack et al. 1981). However, at a 20 $\mu\text{g/g}$ cadmium treatment level, mallards accumulated slightly lower liver and kidney residues of 20 $\mu\text{g/g}$ and 55 $\mu\text{g/g}$, respectively (White and Finley 1978). Histological changes occur between cadmium dietary levels of 20 $\mu\text{g/g}$ to 100 $\mu\text{g/g}$ (White and Finley 1978, Mayack et al. 1981). Low residue levels of cadmium were found in blood, brains, muscle, and gonads in all treatment groups (White and Finley 1978, Mayack et al. 1981). Cadmium residues in duck tissue increased accordingly with the treatment level and time period the ducks were fed the cadmium diets. Thus, a relationship may exist between body levels of

cadmium and environmental contamination (White and Finley 1978, Mayack et al. 1981).

DiGiulio and Scanlon (1984a) examined the relationship of cadmium and lead ingestion in mallards. When seven separate diets consisting of different concentrations of cadmium, lead, and cadmium plus lead were administered to groups of mallards, the kidneys accumulated up to three times more cadmium and lead than the liver at all dietary concentrations of the metals. In dietary treatments including equal concentrations of both metals, cadmium was concentrated fifteen times more by the kidneys and liver than lead. Lead accumulated at similar levels in both the ulnar bones and liver, yet cadmium was not detected in ulnar bones (DiGiulio and Scanlon 1984a). Lead tends to concentrate in calcified tissues (Sharma and Shupe 1977).

Cadmium and lead concentrations were measured in 15 species of ducks obtained from the Chesapeake Bay. In this natural habitat, carnivores (e.g., white-winged scoter, *Melanitta deglandi*, and oldsquaw, *Clangula hyemalis*) accumulated more cadmium in the liver and kidney than brackish-water omnivores (e.g., scaup, canvasback, *A. valisineria*) and freshwater herbivores (e.g., mallard, wood duck). Mean liver concentrations of cadmium in sea ducks ranged from 3.1 to 5.5 $\mu\text{g/g}$, and the kidneys averaged 28 $\mu\text{g/g}$. Cadmium concentrations in livers of freshwater herbivores averaged 0.64 to 1.2 $\mu\text{g/g}$ and 5.7 to 17 $\mu\text{g/g}$ in kidney. Freshwater herbivores, however, retained the highest levels of lead in the liver, ranging from 3.6 to 18 $\mu\text{g/g}$ (DiGiulio and Scanlon 1984b). In comparison, green-winged teal, black-necked stilts (*Himantopus mexicanus*), and American avocets (*Recurvirostra americana*) from a dredge pit accumulated cadmium and lead at levels not significantly different from controls (White and Cromartie 1985).

Prefledgling black-crowned night herons (*Nycticorax nycticorax*) found dead in three Atlantic Coast heron colonies were analyzed for metal contamination. Lead was found in 75 percent of samples and cadmium in less than 50 percent of samples. Investigators proposed that herons from the colony with the highest metal levels in the environment would accumulate higher metal concentrations than herons from the other two colonies. However, the data did not support this hypothesis (Custer and Malhern 1983).

Sources of these metals in duck tissues may vary. The primary source of cadmium in waterfowl tissues seems to be from foods. Spent lead shot usually accounts for the high levels of lead accumulated in tissues, especially in the more highly sought game birds (freshwater herbivores); however, lead-contaminated foods may be an important source of lead in waterfowl tissues. An elevated lead concentration in the liver with relatively low kidney and ulnar bone concentrations generally indicates recent lead ingestion (DiGiulio and Scanlon 1984b).

The adverse impact of environmental lead exposure on waterfowl is well documented (Bellrose 1959, Chupp and Dalke 1964, Sanderson and Bellrose 1986, Mautino and Bell 1987, Eisler 1988, Blus et al. 1989). At least 2 million waterfowl die each year as a result of ingestion of spent lead shot pellets (Eisler 1988). Ingestion of sediment or biota containing lead that originated from mining and smelting processes also contributes to lead poisoning in waterfowl (Blus et al. 1989). Ingestion of lead artifacts accounted for 20 percent of known mortality in trumpeter swans (*Cygnus buccinator*) in Idaho, Montana, and Wyoming. In Washington, 50 percent of known swan mortality was lead-induced. The maximum liver concentration of lead in the

swans was 37 µg/g, and the maximum whole blood concentration was 0.71 µg/g (Blus et al. 1989).

1.3.2.2. Selenium

Selenium is an essential trace element that possesses a narrow range between its beneficial and toxic values. Although the major source of environmental selenium is the weathering of natural rock, selenium enters the environment also through the combustion of fossil fuels and other anthropogenic activities. Selenium metabolism and degradation is significantly modified by interaction with agricultural chemicals, heavy metals, microorganisms, and various physicochemical factors (Eisler 1985b). Dietary selenium is beneficial in animals up to 0.1 µg/g, but toxicity occurs at levels above 4 µg/g (Saiki and Lowe, 1987). The maximum recommended selenium concentration in edible tissue is 1 to 2 µg/g, although the selenium level of concern for waterfowl is ≥ 3 µg/g DuBow (1989). Selenium concentrations will generally increase each succeeding step of the food chain, from water to sediment to plants to animals (Saiki and Lowe 1987).

1.3.2.2.1. Selenium in Waterbirds

When selenium is leached from agricultural soils into drainage water, toxic levels may be attained in aquatic environments (Heinz et al. 1989). At Kesterson Reservoir in California, poor reproductive success, embryonic mortality, external deformities and adult mortality have been observed in ducks and other aquatic birds (Ohlendorf et al. 1986, Heinz and Gold 1987, Saiki and Lowe 1987). Duck breast tissue collected from Kesterson contained 1.0 to 9.5 µg/g selenium (Ohlendorf et al. 1986). Similar concentrations of 1.3

to 6.2 µg/g selenium were determined in American avocet, black-necked stilt (*Himantopus mexicanus*), and green-winged teal collected from dredge waste pits in Corpus Christi, Texas (White and Cromartie 1985).

Heinz et al. (1987) determined the effects of "environmentally realistic dietary levels of selenium" on the reproduction of mallards. One-year-old drakes and two-year-old hens were fed 0-, 5-, 10-, 25-, and 100-µg/g sodium selenite and 10 µg/g selenomethionine. No significant effects were observed in the sodium selenite diets below 10 µg/g. Eleven of twelve mallards died within 16 to 39 days on the 100 µg/g selenite diet. Ten to 25 µg/g of selenite in the diet produced infertility and other reproductive abnormalities.

Reproductive effects observed in ducks fed a diet containing 10 µg/g of selenomethionine included an increase in abnormal embryos, elevated selenium concentrations in eggs, and a low duckling survival rate. Mean selenium concentrations in plant, invertebrate, and fish at Kesterson ranged from 22 to 175 µg/g. Thus, levels of selenium known to exist in nature, such as those at Kesterson, can induce reproductive failure and mortality in waterfowl.

Heinz et al. (1989) fed mallards a diet supplemented with 0-, 1-, 4-, 8, or 16-µg/g selenomethionine to determine the dietary concentration of selenomethionine which impairs reproduction. The dietary concentration of selenium as selenomethionine necessary to impair reproduction was determined to be between 4 and 8 µg/g. Mallards fed a diet of 16 µg/g of selenium as selenocystine showed no reproductive abnormalities. Additionally, Heinz et al. (1989) suggested that eggs from a wild population containing ≥1 µg/g (wet weight basis) should be evaluated for reproductive impairment.

Selenium can be bioaccumulated in food chains (DuBow 1989). Waterfowl and other marsh birds are susceptible to bioaccumulation of selenium because they are in an upper trophic level in aquatic and estuarine ecosystems. DuBow (1989) derived a bioaccumulation factor of 1,430 for waterfowl. Waterfowl would bioaccumulate 1 µg/g of selenium in breast tissue if surface waters contained 0.7 ppb of selenium.

1.3.2.3. Mercury

Mercury occurs naturally in the environment but also enters aquatic and terrestrial systems from industry, mining, smelting, and agriculture. After the source of pollution has been discontinued, elevated levels of mercury in organisms living in the area may persist for as long as 100 years. Mercury has no known biological function; it is a teratogen, mutagen, and carcinogen and causes embryocidal, cytochemical, and histopathological effects (Eisler 1987). Of all metals, only mercury consistently biomagnifies within the aquatic food chain, thus presenting a potential hazard to humans through consumption of mercury-contaminated species (WHO 1976, Hutchinson and Meema 1987). Organomercury compounds, especially methylmercury, are more toxic than inorganic compounds (Eisler 1987). The body does not rapidly excrete methylmercury. Canada limits total mercury in food consumed by humans to 0.5 µg/g (Annett et al. 1975, Hesse et al. 1975, Hutchinson and Meema 1987). The United States considers fish muscle containing >1 µg/g mercury unfit for human consumption (Hutchinson and Meema 1987).

1.3.2.3.1. Mercury in Waterbirds

Waterfowl accumulate mercury through the consumption of contaminated foods, such as fish or seeds treated with methylmercury and alkyl mercury fungicides (Fimreite 1970, Krapu et al. 1973, WHO 1976). Direct effects from mercury have been reported in fish-eating birds (Hutchinson and Meema 1987). Mercury produces the most damage in neurological tissues, but also accumulates in the liver, kidney, and muscle tissues (Hesse et al. 1975, Heinz 1979).

Experimental studies have shown that low dietary concentrations of methylmercury can reduce reproductive success (reduced hatchability and survival of ducklings) in some bird species. Dietary levels of 3 µg/g methylmercury dicyandiamide fed to adult mallards reduced the number of sound eggs laid, increased duckling mortality, and increased embryonic mortality (Heinz 1974). Three generations of experimental mallards showed decreased reproductive success when fed a diet containing 5 µg/g of methylmercury. When parents were fed methylmercury, duckling behavior was altered. Furthermore, a small amount of eggshell thinning was noticed (Heinz 1979). Haegele et al. (1974) did not show significant eggshell thinning in mallards fed a diet containing metallic mercury. Ford and Prince (1975) and Finley and Stendell (1978) also reported lower hatchability and survival of ducklings in experimental ducks fed diets containing methylmercury. For treated adult breeders fed 3 µg/g, relative tissue mercury levels were: feathers>liver>kidney>breast tissue>brain (Finley and Stendell 1978).

The Wabigoon-English River watershed in northwestern Ontario, which includes Ball Lake and Clay Lake, is one of the more highly mercury-contaminated aquatic systems in North America. Tissues of many aquatic birds sampled from this area in the 1970's exceeded safe mercury levels.

Generally, birds that eat fish and other animal foods accumulate more mercury in their tissues than those that predominantly consume plant foods (Vermeer et al. 1973, Fimreite 1974, Annett et al. 1975, Pearce et al. 1976).

At Clay Lake, mallards, blue-winged teal, common goldeneyes, common mergansers, and hooded mergansers (*Mergus cucullatus*) accumulated in breast tissue mercury concentrations of 6.1, 6.5, 7.8, 6.8, and 12.3 µg/g, respectively (Vermeer et al. 1973). Extreme mercury concentrations noted in breast tissue of the mallard, blue-winged teal, and common goldeneye were 9.4, 9.1, and 14.7 µg/g, respectively (Pearce et al. 1976). Mercury residues in scavengers, fish-eating birds, and other game birds from Ball Lake, Clay Lake, and three other area lakes also exceeded safe levels. Some scavengers and fish-eaters attained concentrations of 100 µg/g in tissues; typical surface feeding ducks averaged 10 µg/g or lower. Furthermore, adverse reproductive effects were observed in mergansers and loons (*Gavia sp.*) on these lakes (Fimreite 1974). Annett et al. (1975) also found that liver and breast samples from common mergansers and common goldeneye collected from the Ball Lake area of the Wabigoon-English River systems contained mercury concentrations exceeding the recommended limits.

Mercury levels below recommended limits have been reported in ducks collected in eastern and western Canada. In Manitoba, breast muscle mercury residues averaged 0.18 µg/g for dabbling ducks and 0.22 µg/g for diving ducks (Driver and Derksen 1980). In eastern Canada, dabbling species averaged 0.15 µg/g and diving species 0.31 µg/g of mercury in breast muscle (Pearce et al. 1976). These concentrations were below the 0.5 µg/g safety level recommended in Canada.

In the Cheyenne River watershed in South Dakota, Hesse et al. (1975) reported higher mercury residues in piscivorous species of waterfowl, especially cormorants (*Phalacrocorax sp.*), than in non-fish-eating species. Generally, a greater accumulation of mercury was found in the livers of the fish-eaters and in the kidneys of the non-fish-eaters. Highest mercury levels were determined in the kidneys, livers, and feathers of loons. The cormorant livers averaged 31 µg/g of mercury. Furthermore, these overall values were higher than levels that were previously demonstrated to be reproductively adverse (Frank et al. 1983). In comparison, cormorants sampled from Lake Poinsett, South Dakota, also concentrated the highest residues (mean = 8.0 µg/g) of mercury in the liver (Greichus et al. 1973).

In eastern North Dakota, breeding pintail hens were examined to compare mercury tissue concentrations before and after planting of fields (Krapu et al. 1973). During their nesting season, pintails fed in fields planted with methylmercury fungicide treated seeds. Mercury concentrations in the liver ranged from 0.06 µg/g to 9.5 µg/g, averaging 0.89 µg/g. Liver mercury levels were significantly higher in hens sampled late in the season than hens collected in early spring. The mean mercury concentration was 0.13 µg/g in livers in the preplanting period and 1.17 µg/g in the planting and postplanting periods. Average mercury levels in egg albumen also increased during the season from 0.03 µg/g to 0.31 µg/g (Krapu et al. 1973).

Mercury residues determined in tissues of wood ducks collected on the Holston River in Tennessee were lower than levels reported in several of the regions previously mentioned (Lindsay and Dimmick 1983). Mercury levels averaged 0.42 µg/g (range = 0.13 to 1.10 µg/g) in juveniles and 0.20 µg/g (range = 0.12 to 0.34 µg/g) in adults. Juveniles probably accumulated higher

residues of mercury in their tissues than the adults because their diets include a larger percentage of animal foods. Mercury is biomagnified in the aquatic food chain; thus, the immature wood ducks would accumulate higher concentrations of mercury in their tissues than the adult wood ducks who eat a higher proportion of vegetative matter (Hutchinson and Meema 1987).

Significant relationships have been determined in mercury concentrations between breast muscle and wing muscle, breast muscle and liver, feathers and muscle, feathers and liver, liver and kidney, and kidney and muscle. If the concentration in one tissue is known, the levels in the corresponding tissue can be determined (Vermeer and Armstrong 1972, Fimreite 1974, Pearce et al. 1976, Driver and Derksen 1980). Vermeer and Armstrong (1972) and Pearce et al. (1976) determined correlated ratios of wing muscle to breast muscle in ducks. The mercury concentration ratio for breast muscle to liver was found significant by Hesse et al. (1975), Fimreite (1974), and Driver and Derksen (1980). Furthermore, Hesse et al. (1975) related kidney mercury levels to breast muscle and liver concentrations, and Driver and Derksen (1980) found that feather mercury levels in ducks are ideal for predicting muscle and liver residues.

1.3.2.4. Summary

Muscle tissue, liver, and kidney concentrations of cadmium, lead, selenium, and mercury in waterfowl collected from the United States and Canada have ranged from very low to relatively high in comparison to standard limits. Cadmium, selenium, lead and mercury can induce physiological and reproductive abnormalities in waterfowl when ingested in

elevated concentrations. Residues of these metals, especially selenium and mercury, presently found in some environs of the United States and Canada are elevated enough to cause adverse effects in waterfowl. Livers and kidneys tend to accumulate the highest concentrations of metals in waterfowl.

1.3.3. **REVIEW SUMMARY**

Concentrations of pollutants in organisms inhabiting contaminated areas should be monitored to determine whether the consumption of a contaminated organism would pose a health hazard to humans and whether levels in sediment and water are harmful to biota. As suitable natural waterfowl habitat disappears in the United States, waterfowl and other aquatic birds will increase their use of man-made ponds. The habits of aquatic birds need to be monitored to determine the effects contaminants may induce in bird populations and to insure the safety of humans. Waterfowl and other aquatic birds accumulate radionuclides and metals in tissues; thus, off-site transfer of contaminants demands further evaluation. The movement and interaction of birds using a contaminated area with other local flocks is important in considering off-site transfer of pollutants. Although many studies indicate that human consumption of a contaminated waterfowl is unlikely, the probability of a hunter consuming a contaminated bird needs to be determined in locations close to waste disposal ponds. Furthermore, studies on the influence of diet on the accumulation of pollutants in waterfowl are equally important.

CHAPTER 2

STUDY AREA AND MATERIALS AND METHODS

2.1. STUDY AREA

The federally-owned ORR is located within the corporate limits of Oak Ridge, Tennessee. The three major operating facilities on the ORR are (1) ORNL, (2) the Oak Ridge Gaseous Diffusion Plant (ORGDP), and (3) the Y-12 Plant (Figure 1). ORNL is a multipurpose research laboratory that includes nuclear reactors, chemical pilot plants, isotope production laboratories, and research laboratories. Previously, ORGDP primarily enriched ^{235}U for use as fuel in nuclear reactors. However, because of declining demands for this product, the plant was decommissioned in 1985. Currently, ORGDP is being used as a storage facility for low-level radionuclide wastes and PCB-contaminated wastes. Y-12 primarily produces nuclear weapon components and nuclear materials and provides support to weapons design laboratories and other government agencies. Associated with these functions are the production of lithium compounds, recovery of enriched uranium from scrap material, and fabrication of uranium (Rogers et al. 1988).

The ORR facilities generate several types of waste materials. Radioactive wastes are generated from isotope separation processes, nuclear research activities, uranium processing operations, and reactor operations. Nonradioactive and hazardous wastes are produced by sewage plants, steam plants, cooling towers, acid disposal, and other

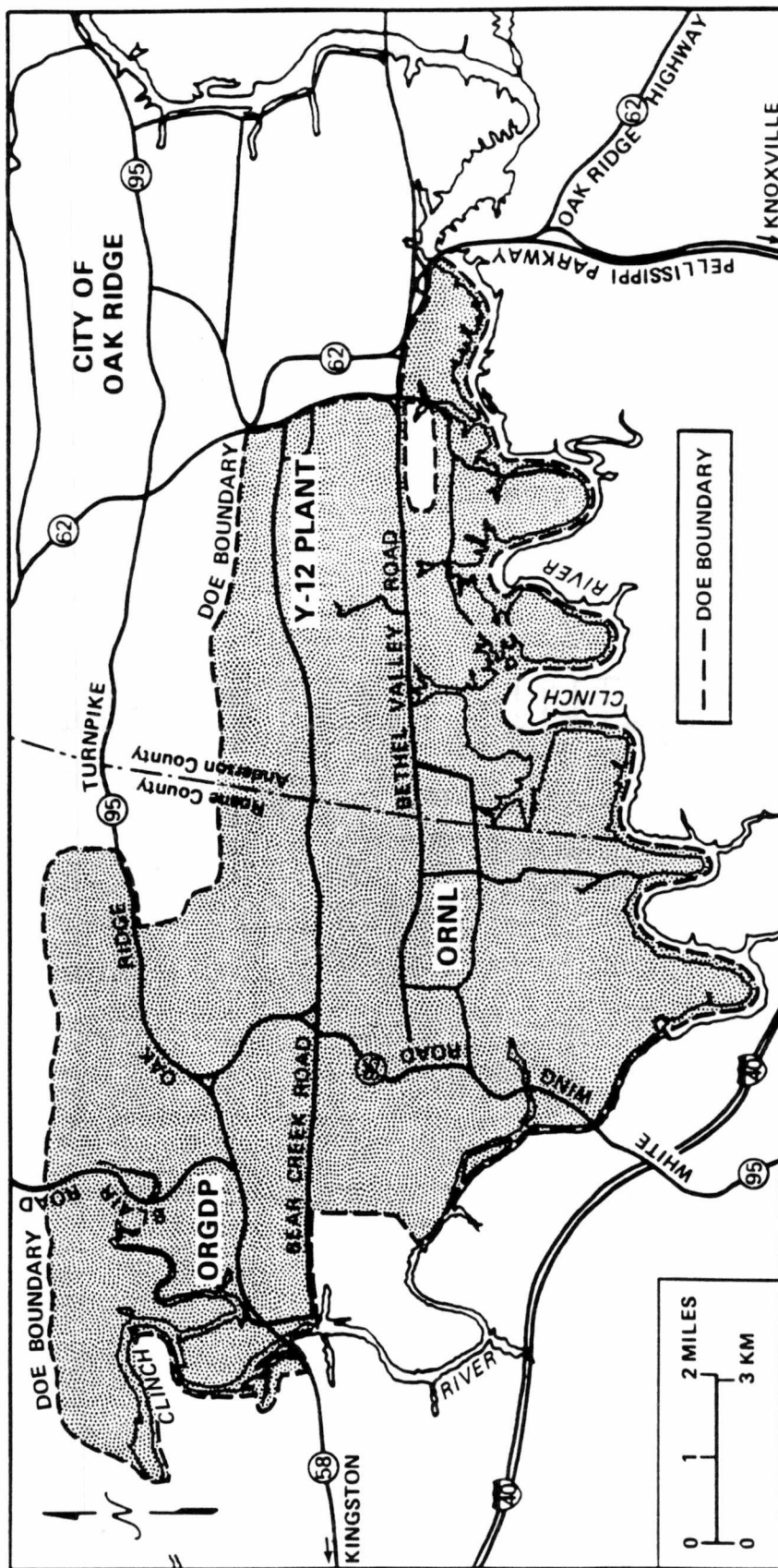


Figure 1. Map showing the Department of Energy's Oak Ridge Reservation, Roane and Anderson Counties, Tennessee, and the location of the three major facilities.

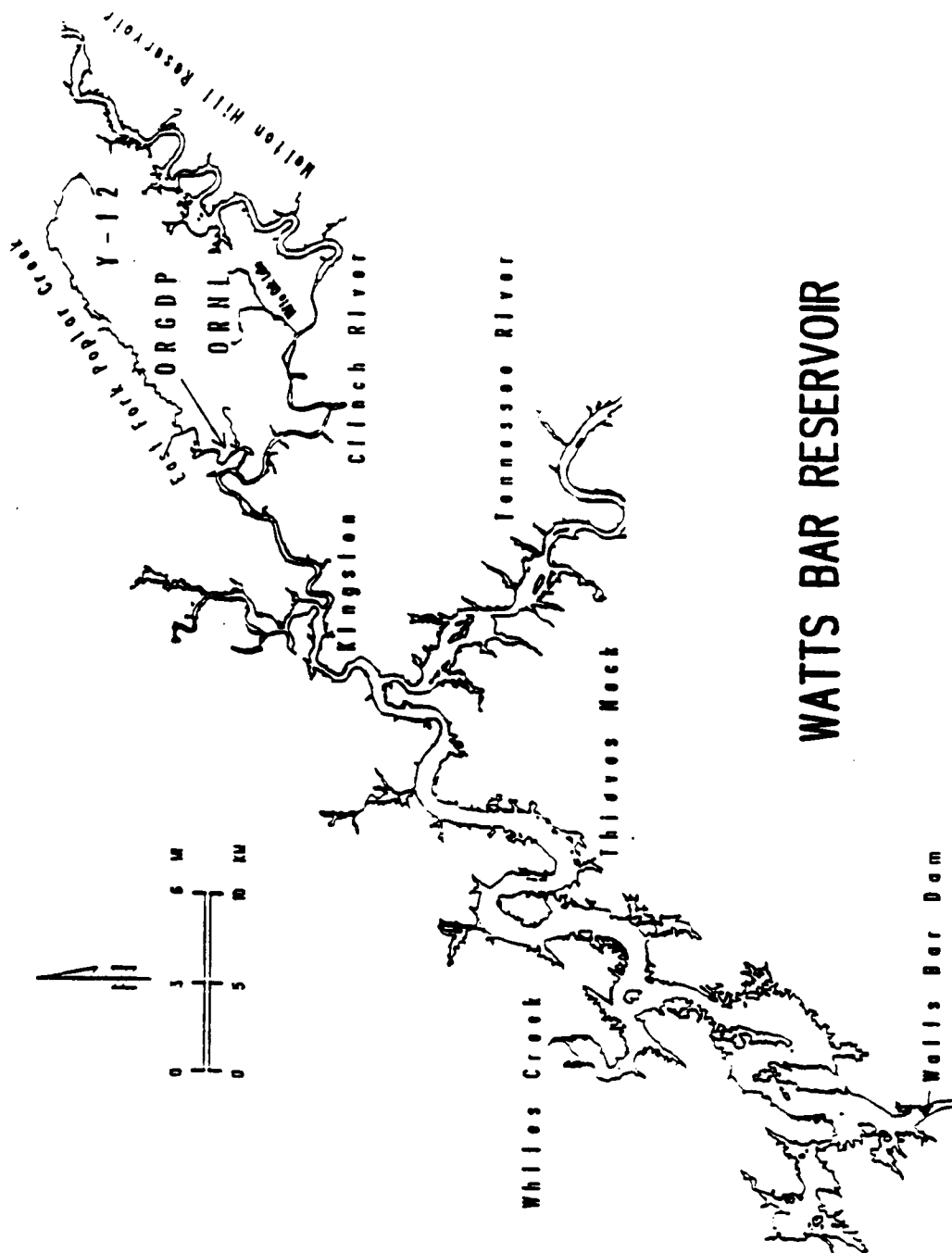
normal industrial support facilities. Wastes are processed and stored on site or are shipped to approved disposal sites off the ORR. Liquid low-level radioactive wastes are treated and then discharged into White Oak Creek, Melton Branch Creek, Poplar Creek, East Fork Poplar Creek, and Bear Creek (tributaries of the Clinch River) (Roger et al. 1988).

The Clinch River receives run-off from the ORR and subsequently conveys it to the Tennessee River. Three TVA dams control the Clinch River's flow: Norris Dam and Melton Hill Dam on the Clinch River, and Watts Bar Dam on the Tennessee River. Backwaters of the Watts Bar Reservoir forms the southwestern and western boundaries of the Reservation. The Melton Hill Reservoir forms the eastern and southern boundaries of the ORR (Loar et al. 1981a, Boyle et al. 1982) (Figure 2).

The habitat for the Clinch River that borders the ORR consists of good cover with submerged tree limbs, tree stumps, and overhanging tree roots and shrubs along both banks. The riparian vegetation zone is narrow with frequent open areas along the banks (Loar et al. 1981a). Macrophyte growth is sparse (Loar et al. 1981a, Boyle et al. 1982).

2.1.1. ORNL

The ORR is composed of a series of drainage basins through which small streams traverse and ultimately reach the Clinch River. The White Oak Creek (WOC) basin, the primary drainage basin at ORNL which includes Bethel Valley and Melton Valley, has a drainage area of 16.8 km². The study sites on the ORNL include ponds, basins, and streams, especially areas associated with the WOC basin (Figure 3). In 1943, WOC



WATTS BAR RESERVOIR

Figure 2. Watts Bar Reservoir and other waterways in relation to the Oak Ridge Reservation.

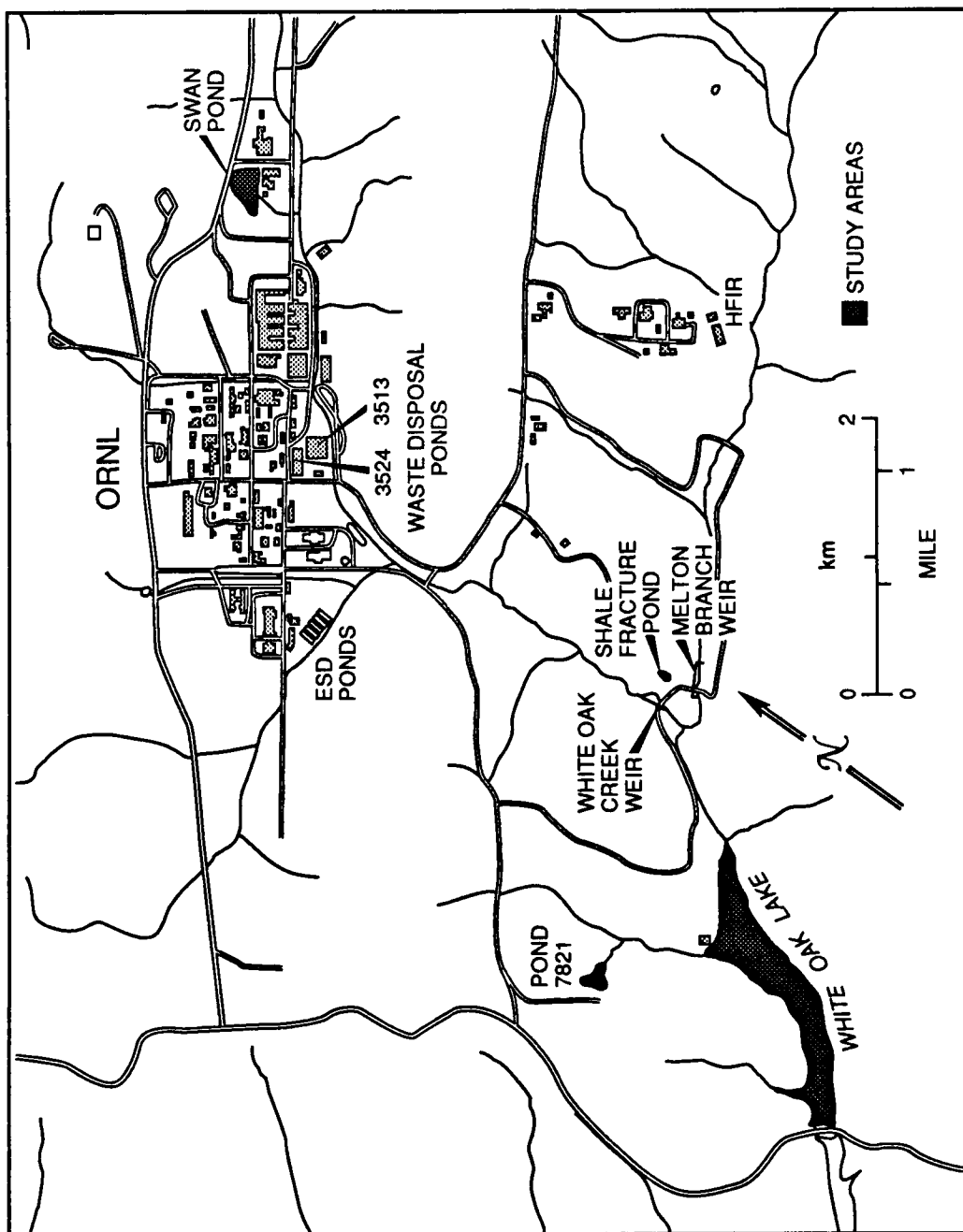


Figure 3. ORNL study area for waterfowl census

was impounded by White Oak Dam, thus creating White Oak Lake. White Oak Lake is a shallow reservoir that serves as the final settling basin for radioisotopes and other contaminants discharged from ORNL (Boyle et al. 1982, Oakes et al. 1982). White Oak Lake is 1 km upstream from the point where WOC enters the Clinch River and 3.7 km downstream from ORNL (Oakes et al. 1982). The eutrophic WOL is approximately 6.88 ha and has an average depth of 0.26 m (Cox et al. 1988). The WOL sediment has been classified as silty clay loam (Lomenick and Gardiner 1965).

White Oak Lake, a primary site for waterfowl on the ORNL, is in an open area bordered by typical wetland vegetation such as sycamore (*Platanus sp.*), pines (*Pinus sp.*), assorted oak species (*Quercus sp.*), ash (*Sorbus sp.*), elm (*Ulmus sp.*), and poplar (*Populus sp.*). Many species of birds and mammals inhabit this area. Periphyte, macrophyte, and benthic invertebrate communities are found throughout the lake and stream (Oakes et al. 1982). Milfoil and duckweed (*Lemna minor* and *Wolffia sp.*) are abundant in WOL, as are filamentous algae (*Spirogyra*) and cattails (*Typha latifolia*) (Loar 1988a, 1989).

The sediment of WOL contains approximately 1.5×10^{13} Bq (405 Ci) of radioactivity, mostly ^{137}Cs , ^{90}Sr , ^{60}Co , and trace amounts of ^{152}Eu and ^{154}Eu . The sediment accounts for 99 percent of all radioactivity in WOL (Loar 1989). Metals (arsenic, beryllium, chromium, lead, silver, thallium, mercury, nickel, cadmium, copper, selenium, and zinc) and PCBs are also found in the sediment (Hoffman et al. 1984). The lake water contains ^3H , ^{90}Sr , and trace amounts of other radionuclides such as ^{60}Co , ^{137}Cs , ^{106}Ru , ^{131}I (Oakes et al. 1982). Radionuclide inventories in the

major compartments of the WOL ecosystem were provided by Loar (1988a, 1989).

White Oak Creek Weir (WOCW) and Melton Branch Weir (MBW) are located above WOL. White Oak Creek Weir is approximately 160 m x 500 m at its maximum width and length. The size of MBW varies considerably with environmental conditions but is much smaller than WOCW. The macrophyte population in both of these weirs is comprised primarily of the same species found in WOL. WOCW contains in sediment approximately 133 kBq/kg (3600 pCi/g) of ^{137}Cs , 2.26 kBq/kg (61 pCi/g) of ^{60}Co , and 4.44 kBq/kg (120 pCi/g) of ^{90}Sr (dry wt.). Melton Branch Weir contains in sediment 3.85 kBq/kg (1040 pCi/g) of ^{60}Co in addition to lower concentrations of 0.63 kBq/kg (17 pCi/g) of ^{90}Sr and 1.85 kBq/kg (50 pCi/g) of ^{137}Cs (dry wt.). Strontium-90 concentrations are higher in water than in sediment for both weirs (Loar 1989).

The old Hydrofracture Facility impoundment is part of the inactive Hydrofracture Facility located at the confluence of Melton Branch and WOC. The facility was used from 1964 to 1979 for the permanent disposal of liquid radioactive waste in impermeable shale formations. The impoundment, which is 30 m long, 6 m wide, and 1 to 2 m deep, served as an emergency containment basin for possible spillage of grout. The impoundment received radioactive grout in 1965 and 1977. In the winter of 1984-85, the impoundment received drill cuttings and drilling fluid from exploratory core boring (Francis et al. 1986). Analyses indicated that contaminant levels in water were below National Interim Primary Drinking Water Standards (NIPDWS) except for selenium, PCBs, ^{137}Cs , and ^{90}Sr . Cesium-137 and ^{90}Sr levels were approximately 4000 Bq/L (109 pCi/ml) in water. In

sediments, metal and PCB concentrations were generally below Resource Conservation and Recovery Act (RCRA) maximum allowable concentrations. Inventories of ^{137}Cs and ^{90}Sr in sediments were 2370 GBq (64 Ci) and 737 GBq (737 Ci), respectively (Francis et al. 1986).

Also located within the ORNL plant is a series of unlined waste impoundments that received low-level radioactive waste waters from 1944 to 1976 (Stansfield and Francis 1986). These impoundments include Basins 3513, 3524, 3539 and 3540. Basin 3513 measures approximately 220 feet on each side. Inventory of radionuclides in the sediment include ^{137}Cs (5000 GBq or 130 Ci), ^{60}Co (50 Bq or 1 Ci), ^{90}Sr (770 GBq or 20 Ci), and ^{239}Pu (100 GBq or 3 Ci) in addition to lower levels of ^{244}Cm , ^{154}Eu , ^{241}Am , and ^{238}Pu . All regulatory constituents except mercury are below EPA and RCRA maximum permissible limits in sediments. The permissible level of mercury in sediment is 0.2 mg/L. However, the mean mercury concentration in the Basin 3513 sediments is 2.99 mg/L (0.15 - 4.8 mg/l). PCB concentrations range from 3 to 22 mg/kg. The only contaminants in the basin water exceeding maximum allowable limits are Cr, Se, and Ag. The basin water contains approximately 290 Bq/L (7.8 pCi/mL) of ^{137}Cs , 420 Bq/L (11 pCi/mL) of ^{90}Sr , and 910 Bq/L (34 pCi/mL) of ^{90}Sr (beta) (Stansfield and Francis 1986).

Basin 3524 measures 85 m x 24 m with water depths ranging from 0.5 m to 1.2 m. The basin functions as a hold-up, collection, and mixing basin for the process waste treatment system. Radionuclide inventories in sediment are estimated at 3.77×10^{12} (102 Ci) of ^{137}Cs , 1.07×10^{12} (29 Ci) of ^{90}Sr and lower concentrations of ^{60}Co , ^{154}Eu , and ^{241}Am (Braunstein et al. 1984). This pond still receives wastewater from ORNL (Francis and

Stansfield 1986). Basins 3539 and 3540 are smaller holding ponds which receive process waste from Building 4500 complex for monitoring discharges into WOC (Braunstein et al. 1984).

Swan Pond, constructed for aesthetic purposes, is a 1.4 ha pond located outside the ORNL enclosure near the visitors' center. No known contaminants have been released into this pond. Swan Pond is enclosed with a fence.

Two rock quarries, Kerr Hollow Quarry and Rogers Quarry were included during the census but are not shown on Figure 3. Both quarries are actually a part of the Y-12 facility. Rogers Quarry has been used as a waste disposal facility for the Y-12 Plant. The quarries are described in Bogle and Turner (1989) and Haase et al. (1987).

2.1.2. ORGDP

Study sites at ORGDP are Poplar Creek, K-1007 B Holding Pond, K-901 A Holding Pond, three small holding ponds bordering Highway 95, areas inside the ORGDP enclosure including Holding Ponds K-1420, K-1037, K-1407 B, and the extensive grassy areas at ORGDP (Figure 4). The primary contaminants detected in ORGDP aquatic systems are uranium, nickel, mercury, cadmium, chromium, copper, lead, manganese, selenium, zinc, technetium, PCBs, and other organics (Loar et al. 1981b, Ashwood et al. 1986). In sediment analyses for these locations, several contaminants were found in concentrations exceeding ORGDP mean levels:

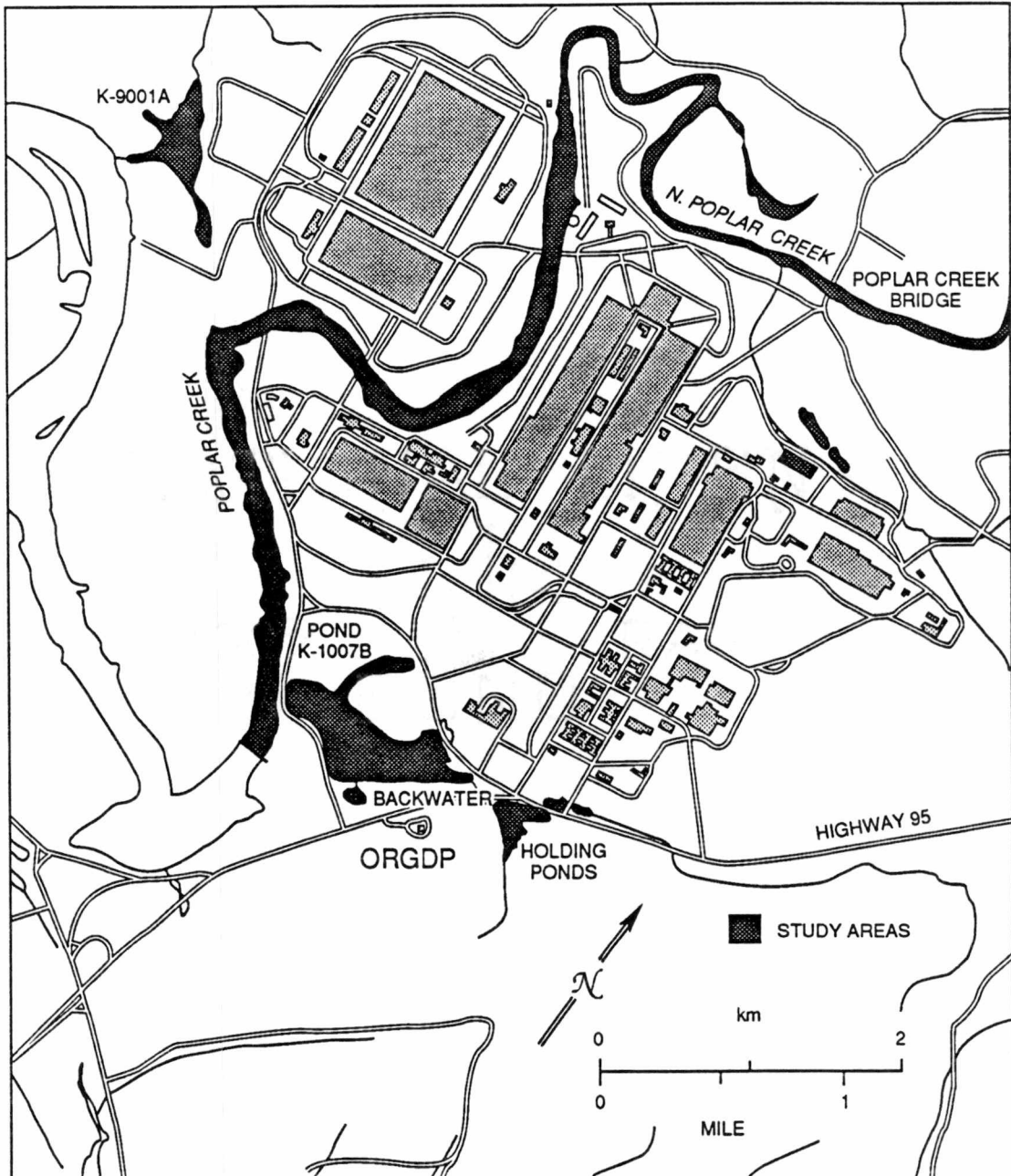


Figure 4. ORGDP study area for waterfowl census.

- (1) Poplar Creek - silver, cadmium, chromium, mercury, selenium, zinc, several organics, PCBs, and radioisotopes;
- (2) K-1007 B Holding Pond - silver, cadmium, chromium, PCBs, and ^{238}U ;
- (3) K-9001 A Holding Pond - chromium, selenium, zinc, some organics, and PCBs

(Loar et al. 1981b, Ashwood et al. 1986).

Poplar Creek, the largest tributary of the Clinch River between Melton Hill Dam and the northwestern boundary of the ORR, flows through ORGDP for a distance of 10 km. The Poplar Creek drainage basin is 352 km². Poplar Creek is affected by releases from ORGDP, ORNL, Y-12, West Oak Ridge Sewage Treatment Plant, and upstream effluents. The habitat of Poplar Creek is typical of most riverine systems in east Tennessee with a nearly closed canopy of sycamore, ash, red maple, and other tree species. In the lower reaches of the creek, habitat for aquatic species is formed by periodic flooding of riparian vegetation (Loar et al. 1981a).

2.1.3. Y-12 Plant

The study area at the Y-12 Plant consists of the former site of New Hope Pond, East Fork Poplar Creek (EFPC), Lake Reality, and grassy areas outside the fence surrounding the Y-12 Plant (Figure 5). The Y-12 facility is located at the headwaters of EFPC and Bear Creek (BC), which flow to the west and east, respectively, of the Plant. The EFPC drainage basin, located near the northern boundary of the ORR, has an area of 77.2 km² from the headwaters to the mouth (Rogers et al. 1988, Loar 1988b).

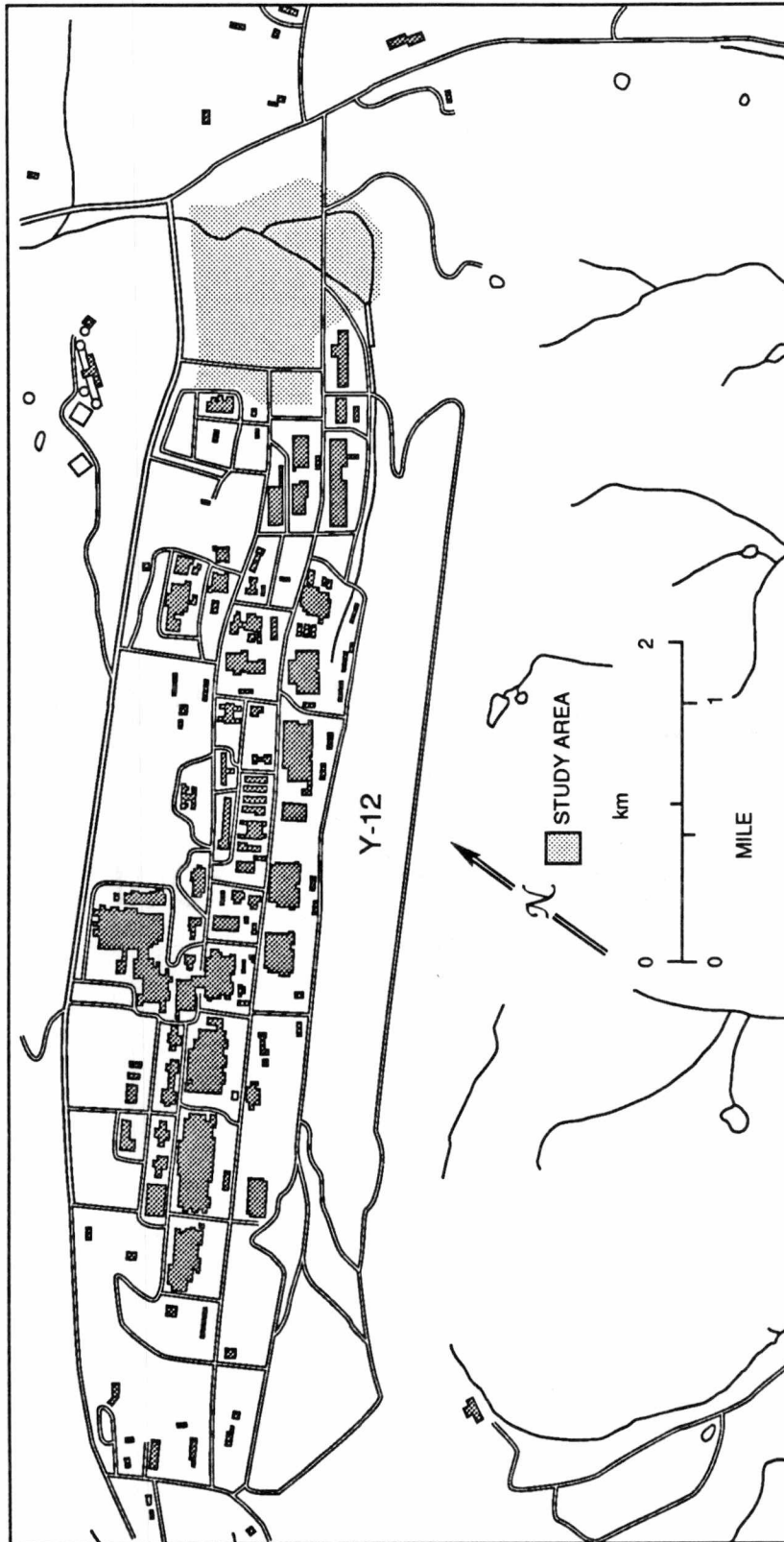


Figure 5. Y-12 Study Area for Waterfowl Census

EFPC leaves the ORR at river km 36.5 and flows through the city of Oak Ridge. EFPC then re-enters the ORR at river km 3.5. Parallel northeast-trending ridges form the northern and southern boundaries of the Y-12 Plant (Loar 1988b).

Streamside vegetation varies along areas of EFPC associated with the study sites. The canopy varies from open to dense. Vegetation ranges from pasture to shrubs, willows, and hardwoods (Loar 1988b).

East of the plant boundary, EFPC previously flowed into New Hope Pond. However, New Hope Pond was drained and rerouted in 1988 to a new basin called Lake Reality (Peterson 1990). New Hope Pond, a 2.2 ha impoundment, was constructed in 1963 for equalization of pH in Y-12 Plant effluents, neutralization, sediment retention, and spill control. From the outfall of New Hope Pond, EFPC flowed 23.7 km to the confluence of Poplar Creek. New Hope Pond outfall was monitored for specific parameters. The outfall contained ammonia, cadmium, copper, and mercury (Loar 1988b).

EFPC water and sediments downstream from the Y-12 Plant contain metals, organics, and radionuclides. Pollutants exceeding background levels in EFPC water were lithium and mercury. EFPC sediment, however, contains PCBs, arsenic, cadmium, lead, mercury, nickel, silver, zirconium, polycyclic aromatic hydrocarbons (PAHs), and bis (2-ethyl hexyl) phthalate in concentrations above background levels and/or above the analytical detection limits (Loar 1988b). From 1950 to 1966 approximately 250,000 kg of mercury was lost to EFPC. Fine surface sediments in EFPC currently contain greater than 300 $\mu\text{g/g}$ of mercury near the point where the creek leaves the plant (Peterson 1990).

2.2. MATERIALS AND METHODS

2.2.1. WATERFOWL CENSUS

A weekly census was conducted to provide an estimate of the species composition and density of the waterfowl using the ponds, lakes, and streams at the ORR. The census for the ORNL reservation was initiated in October 1987 for locations identified as potential areas for waterfowl habitat. Although the census initially included only ORNL, the study was later expanded to include the ORGDP and the Y-12 Plant. Locations at ORGDP were added to the observations in October 1988 and areas at Y-12 in February 1989. The census will continue through 1991.

The weekly waterfowl census was conducted by visiting the locations at ORNL, ORGDP, and Y-12. Observations were made between 0800 and 1300 hours. Binoculars (7x42) or a spotting scope (20x) were used to observe waterfowl to determine species composition and density. The time of arrival at each location was recorded in addition to the current weather conditions. Any unusual occurrences or conditions during observations were also noted, such as human activity at a site.

2.2.2. CANADA GEESE BANDING AND MOVEMENT STUDY

Canada geese using the ORR and adjacent areas were banded to determine their movement patterns and the interaction of ORR geese with other local flocks. The geese were leg-banded in July 1988 in cooperation with the Tennessee Wildlife Resources Agency (TWRA) and the University

of Tennessee. Numbered leg bands were provided by the U.S. Fish and Wildlife Service. Geese were banded at ORGDP, Y-12, ORNL, and Clark Center Park (Figure 6). Breast feathers from each banded goose were collected and analyzed for gamma radionuclides. The geese collected at ORNL were live whole-body counted for two minutes on a sodium iodide (NaI) detector. Eleven geese were sacrificed due to the elevated levels of radionuclides detected in their tissues.

On June 19, 20, 1989, the banding operation of ORR Canada geese was repeated. A health physicist screened the birds for radioactive contamination before they were handled. Corresponding leg-bands and neck-collars were fitted to each adult and several immature birds. Leg-bands that had been fitted previously to the geese were removed. The white neck-collars provided by the U.S. Fish and Wildlife Service are made of a thin, hard plastic and coded with a sequence of letters and numbers (e.g., A01A). The numbers on the neck-collar match the last two numbers on the leg-band. Furthermore, the last letter on the neck-collar corresponds to a specific banding site. Geese were banded at ORGDP, Y-12, ORNL, Clark Center Park, Solway Park, and Melton Hill Dam (Figure 6).

As in 1988, the birds banded at ORNL were live whole-body counted on a NaI detector for five minutes to check for elevated levels of radionuclides. Radionuclide levels for the thirteen geese did not significantly exceed background levels. On July 11, 1989, however, when a group of banded and unbanded Canada geese that frequented the sewage treatment ponds at ORNL were captured and live whole-body counted, six of the banded birds were sacrificed due to elevated levels of

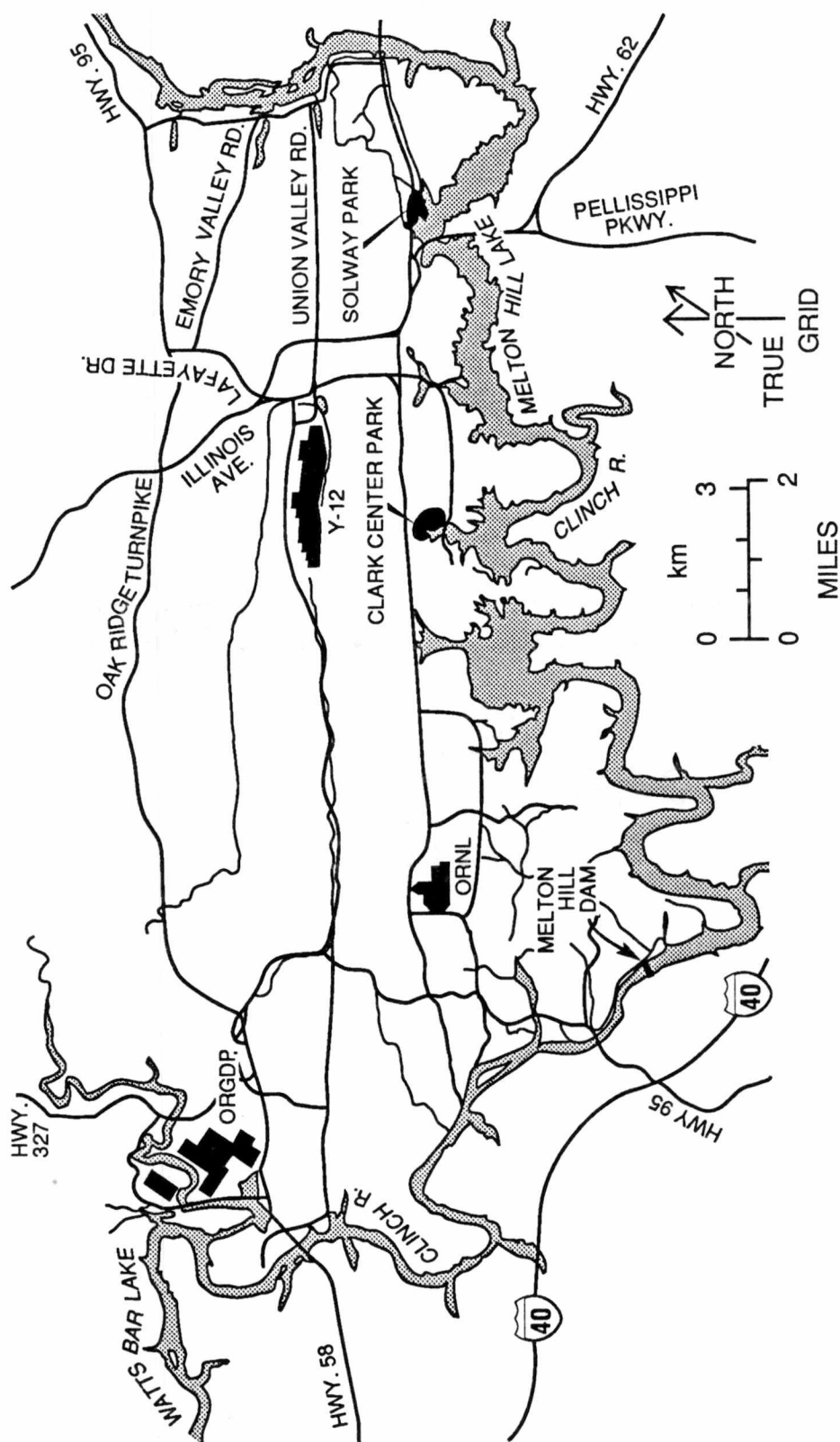


Figure 6. Map showing Canada geese banding sites on the Oak Ridge Reservation and surrounding areas.

radionuclides. The remaining unbanded geese were fitted with leg-bands and neck-collars.

Hunter and road-kill reports were the only source of information on the 1988 banded geese. The use of neck-collars in 1989 allowed for regular observations of the geese and for association of a goose with a particular area during its flightless period. During the weekly waterfowl census of the ORR, the collar numbers on banded geese, their activity, location of observation, date and time of observation were systematically recorded on data sheets provided by a program created at the University of Wisconsin (Rusch and Swenson 1987). The number of weekly census sites increased to 30 locations for Canada geese as areas frequently used by geese were added. In addition, a 50 mile section of the Clinch River - Melton Hill Reservoir between Clinton and Kingston, Tennessee was censused monthly by boat to observe collared geese (Figure 7).

2.2.3. CONTAMINANTS IN ORR WATERFOWL AND COOTS

2.2.3.1. Wild Waterfowl and Coots

To determine the contaminants accumulated in tissues of waterfowl and coots using the ORR, a total of 61 wild birds was collected between December 1987 and January 1990 (including road-killed Canada geese). The tissues from both transient and resident species, including Canada geese, mallard, wood duck, gadwall, black duck, and American coot were analyzed for pollutants. Birds were collected with traps or firearms.

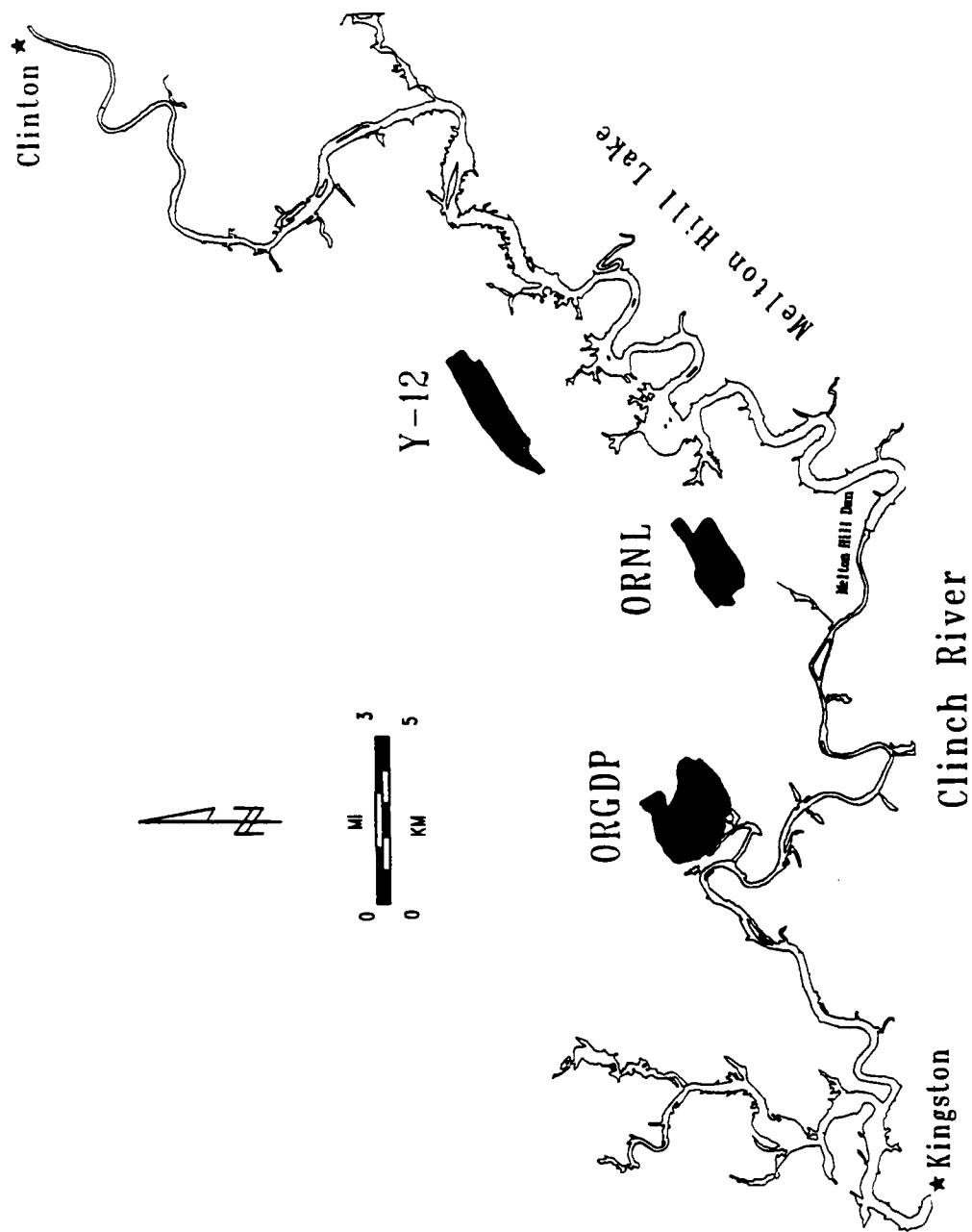


Figure 7. The section of the Clinch River and Melton Hill Reservoir censused for Canada geese.

Each bird was placed in a plastic bag for transportation to the laboratory. Species, sex, body weight, location of collection, age, and general condition of the bird were recorded. Carcasses were either processed immediately or frozen until dissection. Breast tissue, liver, kidney, bone, gastrointestinal tract and gizzard, gizzard contents, and skin and feathers were sampled. Because of the varying conditions of the road-killed Canada geese, only breast tissue, liver, and some kidneys were extracted. Tissues were placed in plastic, aluminum, or glass containers (depending on analysis to be performed and amount of tissue) and weighed. The duck and geese tissues were then analyzed for radionuclide and metal contaminants.

An intrinsic germanium detector coupled to a Nuclear Data 6700 microprocessor system was used for gamma radionuclide determinations. The modified Nuclear Data program allowed for an automated peak search routine, corrections for background, identification of radionuclides by gamma-ray signatures, activity calculations, and correction for decay based on the elapsed time interval between the sample collection and sample analysis dates (Ashwood et al. 1986). The radionuclide activity was reported in becquerels (Bq), which is the basic Standard International (SI) unit of radioactivity. One Bq is equal to 1 disintegration/second and 27 pCi (old units) (NCRP 1985).

The ORNL Analytical Chemistry Laboratories performed analyses for ^{90}Sr (beta-emitting radionuclide) and metals. Mercury analyses were conducted using the ACD procedure EC 420. Samples were digested in a mixture of perchloric acid, nitric acid, potassium dichromate. Mercury was then reduced with stannous chloride and determined by cold vapor atomic

adsorption spectrophotometry. Analyses for other metals were conducted with graphite furnace atomic absorption spectrophotometry following digestion with concentrated nitric acid (Loar 1988a).

Radionuclide concentrations were determined for whole body, breast tissue, liver, kidney, gastrointestinal tract and gizzard, gizzard contents, bone, and feathers. Radionuclide and metal concentrations are reported on a wet weight basis. Concentrations of metals, including mercury, cadmium, chromium, silver, lead, arsenic, and selenium, were determined in breast muscle, liver, and kidney. Initial samples were also analyzed for chromium, copper, lithium, beryllium, thallium, molybdenum, nickel, and zinc but discontinued for all other samples because levels were below limits of detection or very low.

The concentrations of ^{137}Cs , cadmium, mercury, and selenium in breast tissue and ^{90}Sr in bone were tested among species and year of collection. SAS statistical procedures were used to analyze the data (SAS Institute 1985a, SAS Institute 1985b). A one-way analysis of variance (ANOVA) was used to test for significant seasonal differences for each species separately where possible. In addition, for the 1988-89 and 1989-90 data, a one-way ANOVA was used to evaluate species differences for the five responses (Zar 1984). Seasonal differences among gadwalls were not tested because they were only collected in 1988-89. Differences among species were not tested for 1987 because only mallards were collected that year. The tests were not powerful because of the unequal and small sample sizes. A level of $p < 0.05$ was used for statistical significance.

Reference measurements of radioactivity in waterfowl tissues were obtained for comparison purposes from area lakes: Ft. Loudoun, Norris, Tellico, Watts Bar, and Melton Hill. Waterfowl carcasses from these local areas were purchased from a local taxidermist and whole body was analyzed for radioactivity.

2.2.3.2. WOL Wood Ducks

Wood ducks were collected from WOL to determine contaminants in a population that nests in this location. Ten wood ducks were collected from WOL between April and October 1989. Seven of these birds were immature; thus, they have spent at least the first 8 to 10 weeks of their life at WOL. Tissues were processed and analyzed as previously described. The contaminants of concern were ^{137}Cs , ^{60}Co , ^{90}Sr , selenium, mercury, and silver.

SAS statistical procedures (SAS Institute 1985b) were utilized to compare the mean concentrations for the two age groups (immatures and adults) for ^{137}Cs , cadmium, mercury, and selenium in breast tissue, liver, and kidney as well as ^{90}Sr in bone. However, a preliminary test was done to test for the homogeneity of variance. If heterogeneity of variance was found, then Satterthwaite's approximation (Satterthwaite 1946) for the two-sample t-test was used (Zar 1984). If $p < 0.05$, then a significant difference was determined between the immatures and adults for that particular response. For the purpose of statistical analyses, concentrations below detection limits were assigned the value of the limit of detection.

2.2.3.3. WOL Domestic Mallard Experiment

To establish accumulation rates of radionuclides and metals in waterfowl tissues, 76 domestic wing-pinioned mallards were released on WOL. The ducks were among 80 that were purchased from a commercial mallard farm in Illinois and maintained for one week prior to release in an enclosed area at an uncontaminated site. Thirty-eight birds were released May 6, 1989 and thirty-eight birds were released October 14, 1989. Two mallards from each group were also sacrificed as controls before release. Two releases of 38 mallards each were scheduled so that the first group of mallards could remain on the lake for approximately 6 months to simulate a resident population. The second release of birds paralleled the arrival of fall transient birds on the lake. This release allowed for the testing of seasonal differences in tissue concentrations and also provided a second opportunity for the determination of pollutant concentrations in tissues.

Ducks were fitted with sequentially numbered leg bands. Fluorescent-colored neck-collars were fitted to the first group only. The first mallard group would get their bills caught in the collars while preening or pecking at the band. Neck-collars were omitted for the second group to improve their chance of survival. The neck-collars were used to distinguish the domestic mallards from any transient mallards in the field. The weight and sex of each bird were recorded before release.

All birds were of the same age in the first group released. Because trapping efforts with "HAVA Heart" traps were not successful for this group, ducks were collected with firearms. One mallard was sampled on each of days 2, 4, 49, and 77, and three birds on days 9 and 21.

The second group of mallards consisted of 20 immatures and 20 adults. These mallards were sampled on days 2, 4, 8, 16, 33, 39, 61, and 95. Firearms were used to collect the ducks. Three or four mallards were sacrificed per sampling period, except for day 33 and 95, when one bird was sampled. The day 95 duck had regained its ability to fly and was collected with a group of transient waterfowl.

The ducks were placed in a plastic bag for transportation to the laboratory. The dissection was conducted on the day of collection when possible. Tissues were frozen prior to analyses. Radionuclide and metal analyses were conducted on the tissues as mentioned in the previous section.

The SAS statistical program (SAS Institute 1985) was used to conduct statistical analyses on the contaminant uptake data from the domestic mallards released on WOL. The relation of contaminant concentration in tissues versus time was compared for each group. The regression equations for each group were compared using the residual or error sum of squares to determine if the two groups differed significantly ($p < 0.05$) (Zar 1984). If the regression lines did not differ significantly for each group, the data were pooled and a common linear regression model was estimated. Those data that differed significantly were analyzed separately. For each situation (separate or pooled groups), the lack-of-fit test was used to evaluate the adequacy of the resulting model. If the linear model was not adequate for the data, a quadratic model was fit to the data and the lack-of-fit test was used to evaluate the adequacy of the resulting model (Kleinbaum et al. 1988). For those responses below the limits of detection, the detection limits were used as an estimate for that response.

The contaminant concentration versus time was evaluated for ^{137}Cs and ^{60}Co in whole body, ^{137}Cs and mercury in breast tissue, ^{137}Cs and mercury in liver, ^{137}Cs and mercury in kidney, and ^{90}Sr in bone. Cadmium, selenium, lead, and silver concentrations in mallard tissues versus time were too variable to adequately present the uptake data.

2.2.3.4. Dose to Humans

The potential dose to a human from consuming a duck contaminated with radionuclides accumulated from the waste ponds or streams at the ORR were calculated as follows:

- (1) ^{137}Cs breast tissue concentrations were used for whole-body effective dose equivalent calculations;
- (2) dose conversion factors were from Gilbert et al. (1985);
- (3) waterfowl were assumed to be killed and eaten the day they left the ORR;
- (4) doses were based on weight before cooking;
- (5) radioactive decay, volatilization, and biological elimination of radionuclides during cooking were not considered in dose calculations (Halford et al. 1981);
- (6) edible tissue (muscle tissue and liver) was determined to be approximately 35 percent of live duck and goose weight;
- (7) doses were based on the consumption of 1600 grams of goose flesh or 35 percent of a duck's body weight .

Residues of metals in breast tissue, liver, and kidney of ORR ducks and geese were compared to suggested limits in Lappenbusch (1988) and

other literature values to estimate the potential hazard to humans from the consumption of a duck contaminated with metals.

CHAPTER 3

RESULTS

3.1. WATERFOWL CENSUS

More than 16,000 observations of waterfowl have been recorded for the designated locations at the ORR since the waterfowl census began in October 1987. Fifteen waterfowl species, including dabbling ducks, diving ducks, mergansers and geese were observed on the waste ponds and associated areas at the ORR (Table 1). Both resident and transient birds used the ORR. Resident species included Canada geese, wood duck, and mallard. Transient or migratory waterfowl observed on the ORR were black duck, gadwall, ring-necked duck, mallard, blue-winged teal, green-winged teal, American wigeon, hooded merganser, bufflehead, scaup, and red-breasted merganser. Canada geese were the most abundant species. Other aquatic bird species using the ponds, lakes, and streams at the ORR were American coot, pied-billed grebe, belted kingfisher, green-backed heron, great blue heron, black-crowned night heron, little blue heron, ring-billed gull, and great egret. Because waterfowl were not captured or marked, residence time was not established. However, some of the waterfowl were believed to stay on the ponds for extended periods but, because they could not be positively identified, they were counted each week as a new observation.

The distribution of waterfowl varied from pond to pond, probably as a result of the influx and efflux of migrating birds and the nesting behaviors of individual species. The greatest abundance of waterfowl was observed at the

Table 1. Species of waterfowl and other waterbirds observed at ORR related aquatic systems.

Common Name	Scientific Name
American Black Duck	<i>Anas rubripes</i>
American Coot	<i>Fulica americana</i>
American Widgeon	<i>Anas americana</i>
Belted Kingfisher	<i>Megaceryle alcyon</i>
Black-Crowned Night Heron	<i>Nycticorax nycticorax</i>
Blue-Winged Teal	<i>Anas discors</i>
Bufflehead	<i>Bucephala albeola</i>
Canada Goose	<i>Branta canadensis</i>
Gadwall	<i>Anas strepera</i>
Great Blue Heron	<i>Ardea herodias</i>
Great Egret	<i>Casmerodius albus</i>
Greater Scaup	<i>Aythya marila</i>
Green-Backed heron	<i>Butorides striatus</i>
Green-Winged Teal	<i>Anas crecca</i>
Hooded Merganser	<i>Mergus cucullatus</i>
Lesser Scaup	<i>Aythya affinis</i>
Little Blue Heron	<i>Florida caerulea</i>
Mallard	<i>Anas platyrhynchos</i>
Pied-Billed Grebe	<i>Podilymbus podiceps</i>
Red-Breasted Merganser	<i>Mergus serrator</i>
Ring-Billed Gull	<i>Larus delawarensis</i>
Ring-Necked Duck	<i>Aythya collaris</i>
Snow goose	<i>Chen caerulescens</i>
Wood Duck	<i>Aix sponsa</i>

ORR during the late fall and winter. The lowest numbers of waterfowl were observed in the late spring and summer.

3.1.1. ORNL

Since October 1987, approximately 6700 observations of waterfowl have been made at ORNL. White Oak Lake and Swan Pond were the most active ponds with waterfowl and brood pairs. Waterfowl were observed on all other ORNL census locations except for the High Flux Isotope Reactor (HFIR) ponds.

Canada geese, wood ducks, and mallards were not only abundant on the ORNL related aquatic systems, but these species also nested and raised young at these areas. The ORNL geese were probably from a resident population. Canada geese were observed with young at WOL, Basins 3513 and 3524, and Swan Pond. The number of geese at ORNL usually varied between each observations, indicating that the geese did not limit their use of the reservation to one area. Furthermore, ORNL employees have noted Canada geese on WOL in the early evening hours throughout the year, thus indicating that geese may be using WOL as a roosting area.

Wood duck populations thrived on WOL from April to October in both 1988 and 1989. In October 1988, 27 wood ducks were observed during a single census period on WOL, and the number of wood ducks peaked at 56 birds in August 1989 (Figure 8). During both years, the adults arrived on the lake in April, raised their young during the summer, and then most individuals left by October. Several different broods were identified on the lake in 1989.

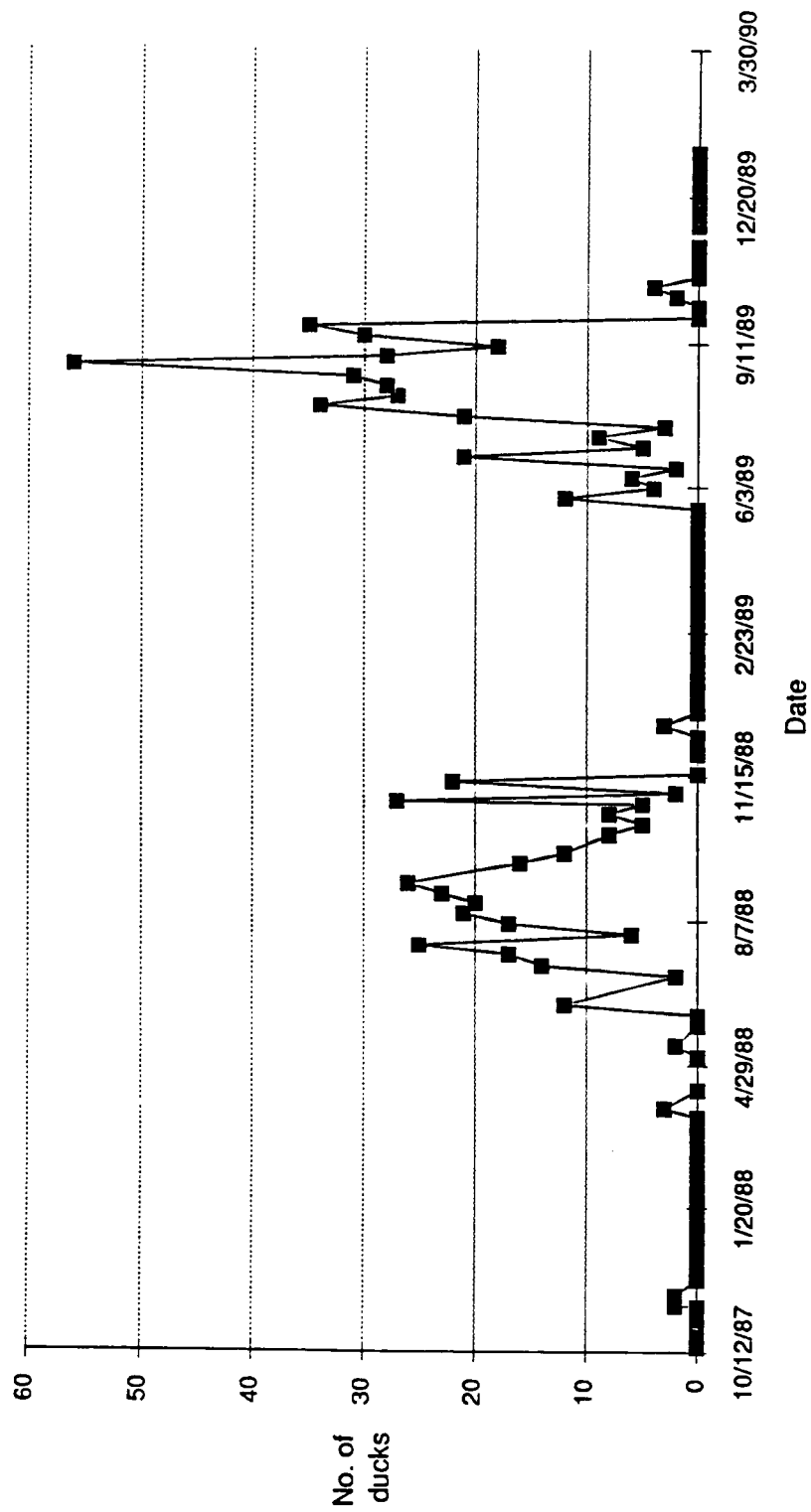


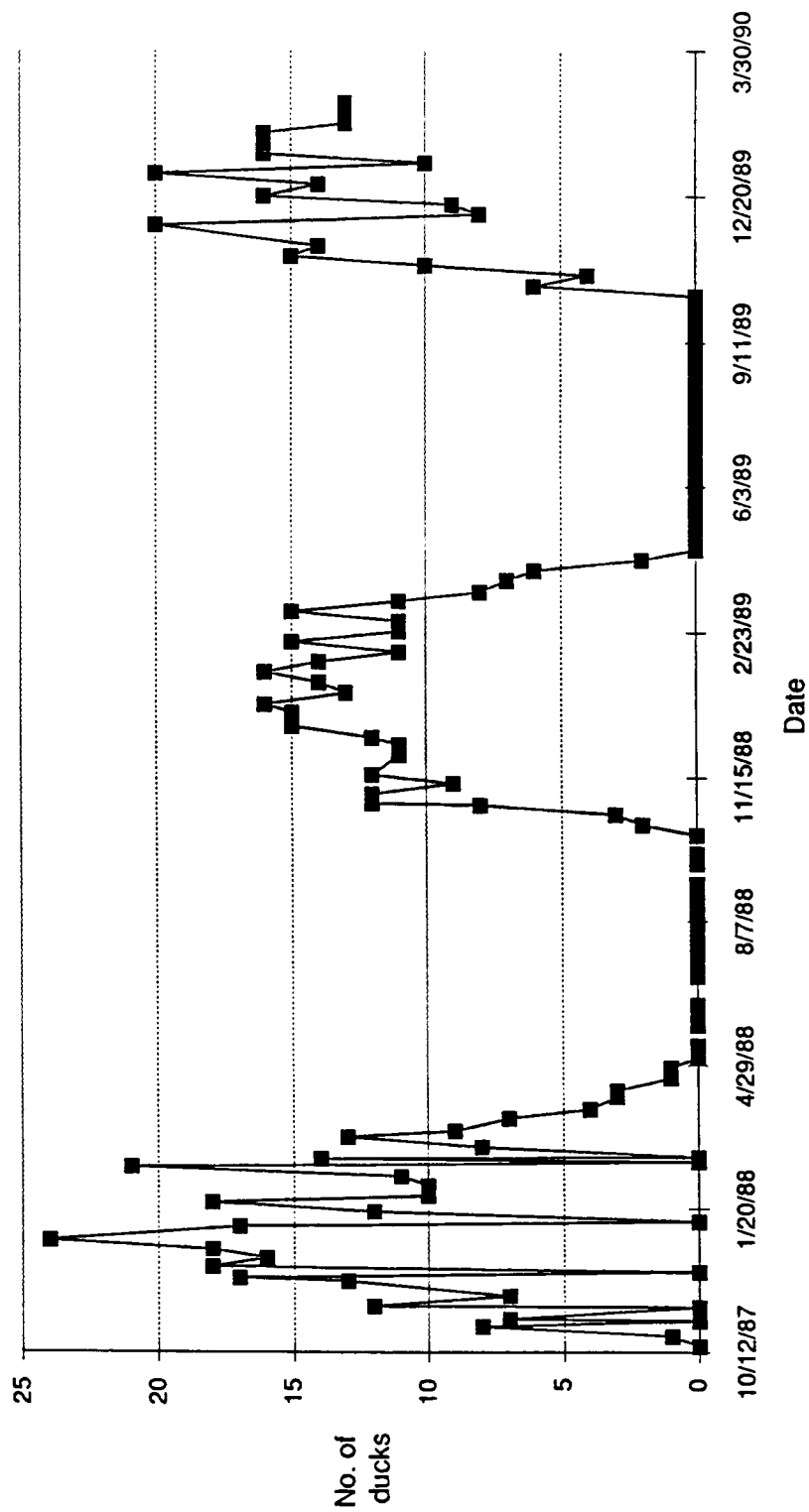
Figure 8. Weekly number of wood ducks observed on WOL.

A resident population of seven mallards resided at the uncontaminated Swan Pond and produced young in 1989. The young have remained on the pond with the adults and the population is now 15 birds. Swan Pond also served as a wintering ground for a population of ring-necked ducks. From 16 to 24 ring-necked ducks used the 1.4 ha pond each season. The ducks arrived in October and remained through April; this trend was observed from 1987 to 1990 (Figure 9). Furthermore, Swan Pond has served as a resting ground for migratory species such as bufflehead, red-breasted merganser, lesser scaup, and hooded merganser. These species were only observed occasionally.

The waterfowl population on WOL fluctuated throughout the year because WOL served as a resting ground and a possible wintering area for migratory species during the fall and winter. The number of waterfowl observed on WOL has ranged from 0 to numbers approximating 160 birds (Figure 10). An individual bird probably spends a few days to several weeks on the lake. Transient waterfowl species observed on WOL between September and March included blue-winged teal, green-winged teal, mallard, black duck, gadwall, hooded merganser, and American wigeon. American coot, pied-billed grebe and several heron species were also observed on WOL. Black ducks, mallards, and gadwalls probably used WOL as a wintering area.

3.1.1. ORGDP

Waterfowl species have been observed at all of the designated ORGDP census locations. Species observed include Canada geese, mallard,



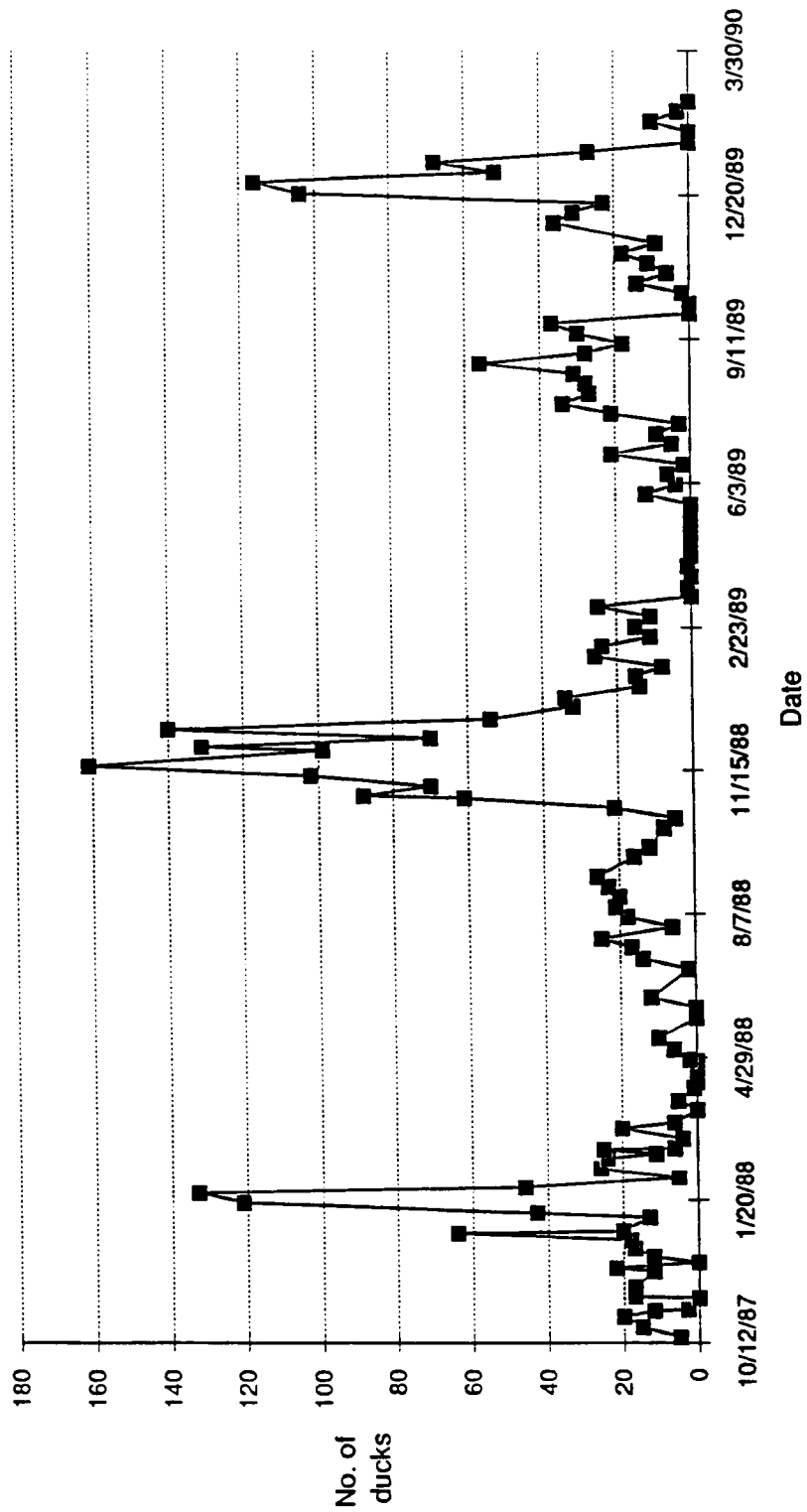


Figure 10. Weekly number of all waterfowl observed on WOL.

gadwall, wood duck, hooded merganser, black duck, blue-winged teal, ring-necked duck, snow goose, and greater scaup. Gadwalls and wood ducks seemed to prefer K-9001 A Holding Pond. Wood ducks also inhabited areas of Poplar Creek from approximately June to December. Furthermore, K-1007 B Holding Pond served as a migratory resting area for blue-winged teal, black duck, gadwall, hooded merganser, ring-necked duck, greater scaup, snow goose, and mallard. This holding pond was most used by ducks during the winter months (Figure 11). The small holding ponds bordering Highway 95 also were used by transient waterfowl. Other aquatic birds using ORGDP ponds were American coot, pied-billed grebe, green-backed heron, great blue heron, black-crowned night heron, and belted kingfisher.

Canada geese used the aquatic areas at ORGDP extensively. Geese have been observed at most of the ORGDP census locations, but the most frequently used sites were Poplar Creek, K-1007 B Holding Pond, the small holding ponds, and the grassy areas throughout the ORGDP reservation. Approximately 6700 observations of geese were recorded with several hundred geese observed at ORGDP during a single observation period (Figure 12). The number of geese observed at ORGDP increased during December and January as migratory birds pass through the area. Most of the Canada geese at ORGDP were probably of a resident population; however, some transient geese used these aquatic systems as a resting area or wintering ground. Resident geese use these same areas for nesting, because goslings were observed in 1988 and 1989.

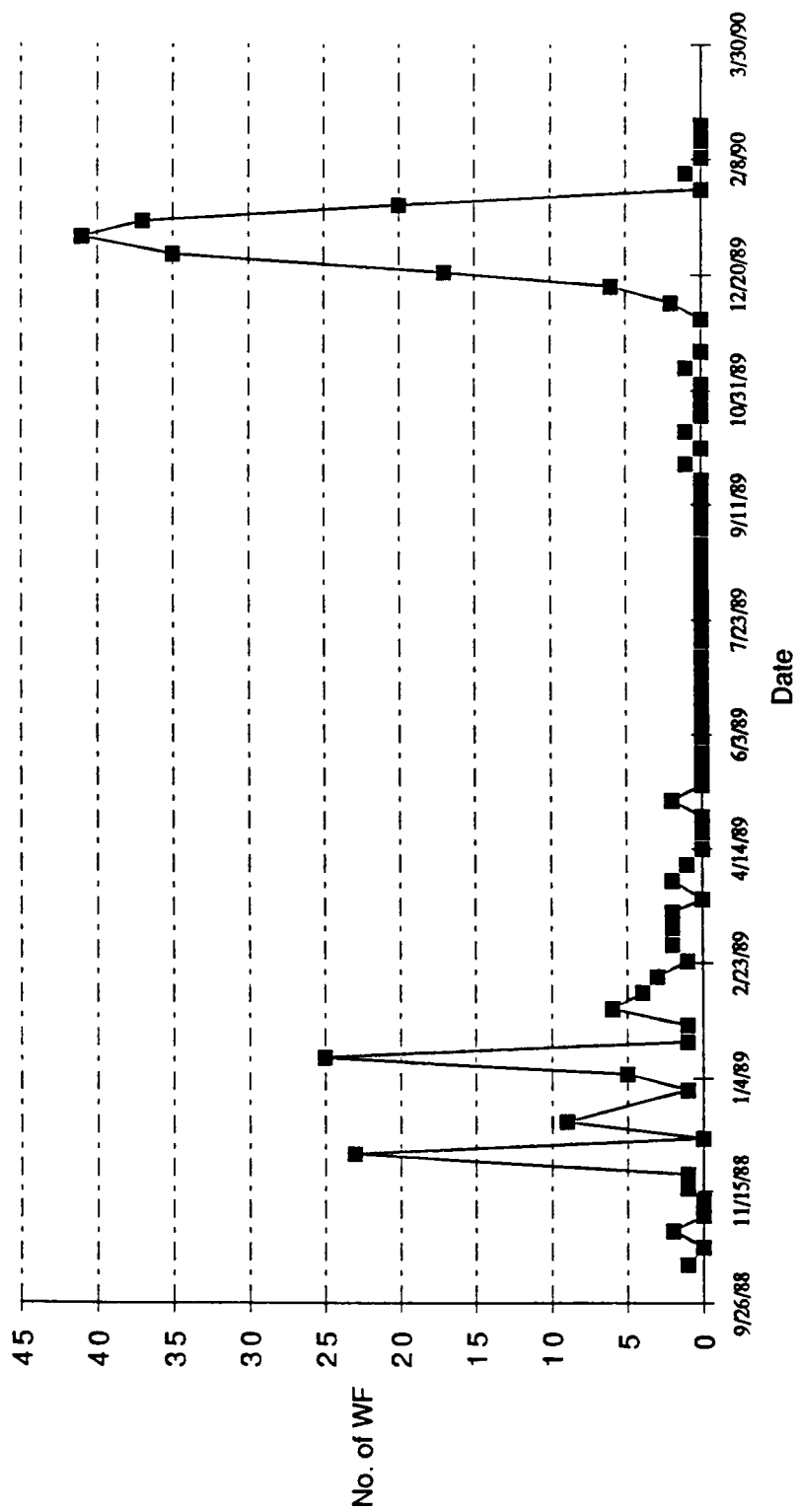


Figure 11. Weekly number of waterfowl, excluding Canada geese, observed on K-1007B holding pond at ORGDP.

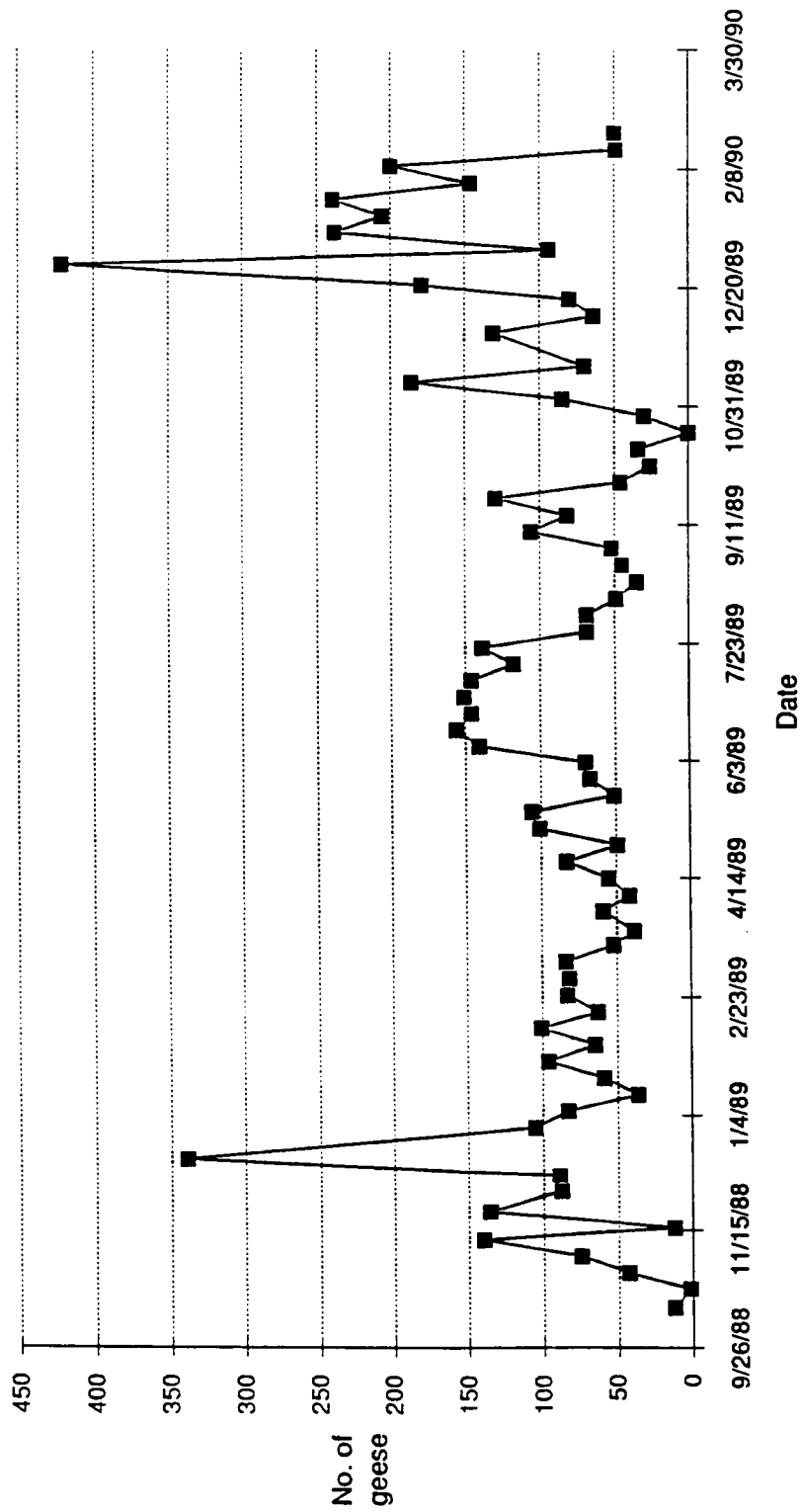


Figure 12. Weekly number of Canada geese observed at ORGDP.

3.1.3. Y-12 Plant

Canada geese and ring-necked ducks were the only waterfowl species observed at censused areas of the Y-12 Plant. Canada geese nested at the Y-12 Plant also. Approximately 2000 observations of geese have been recorded at the Y-12 Plant with nearly 200 geese observed during a single census period (Figure 13). Relatively large flocks of geese were observed between August 1989 and January 1990. These larger groups were probably a combination of migratory and resident geese. The geese preferred the extensive grassy areas outside the main plant, especially the former site of New Hope Pond. The numbers of geese fluctuated throughout the year at the Y-12 Plant probably due to the close proximity of the Y-12 Plant to Clark Center Park and other areas on Melton Hill Reservoir which are inhabited by flocks of Canada geese.

3.2. CANADA GEESE BANDING STUDY

In 1988, 168 Canada geese were leg-banded. Because this banding occurred toward the end of the flightless period for these birds, several geese flew off before they were captured. Only 5 known returns were given for this banded group and harvest data was not received in time for this report. A female goose collected from Basin 3524 at ORNL in March 1989 was leg-banded at ORGDP.

In 1989, 283 Canada geese were leg-banded and fitted with neck-collars and 110 immature birds were fitted only with leg-bands. Forty-five of

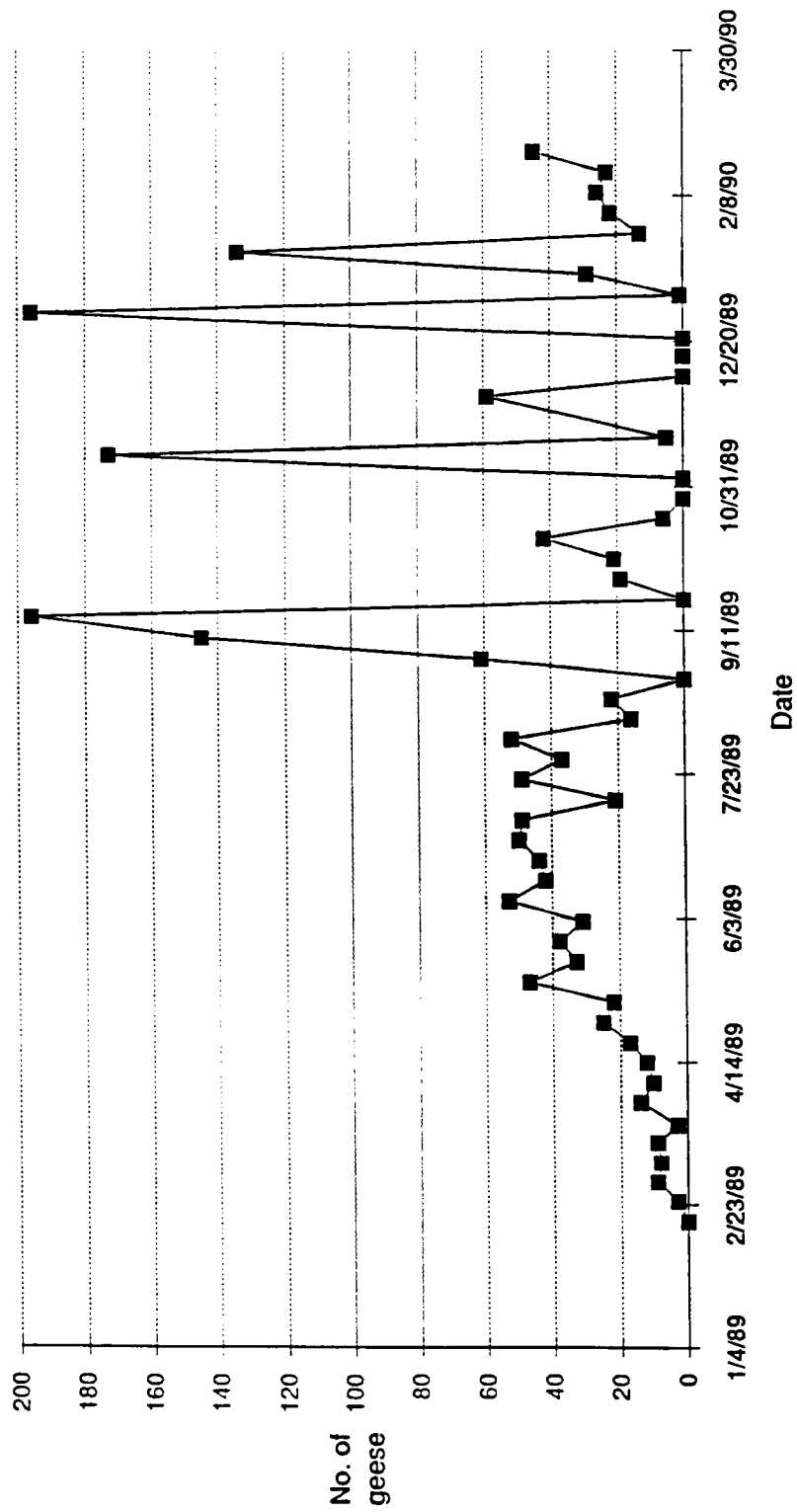


Figure 13. Weekly number of Canada geese observed at the Y-12 Plant.

the geese leg-banded in 1988 were re-captured in 1989 and fitted with new bands.

The black letters and numbers on the white neck-collars allowed for easy identification of the birds in the field with either binoculars or a spotting scope. Usually the collars could be read without disturbing the geese or causing them to fly.

Between June 1989 and April 1990, approximately 1250 observations of collared geese were recorded at ORGDP in comparison to 650 for other areas censused weekly combined. Because of limited data from the monthly census of Melton Hill Reservoir and the Clinch River, the monthly census results were excluded from the analyses. The data from the weekly census of the ORR and associated areas were analyzed together for all observations and then divided into observations of geese collared at ORGDP and observations of geese collared at all other weekly sites. Most of the geese collared at ORGDP were observed within 1 km or less from the initial banding site (Figure 14).

The observations of geese during the weekly census indicate that the total number of geese observed per week remained relatively constant over the study period whereas the number of collared geese per week declined (Figure 15). The ratio of the total number of collared geese observed to the total number of all geese observed supported this trend (Figure 16).

The number of geese observed during the study period at ORGDP decreased, especially after week 34. Although the number of collared geese observed at ORGDP also decreased, this decline was initiated at week 31 (Figure 17). At areas other than ORGDP, the number of geese observed

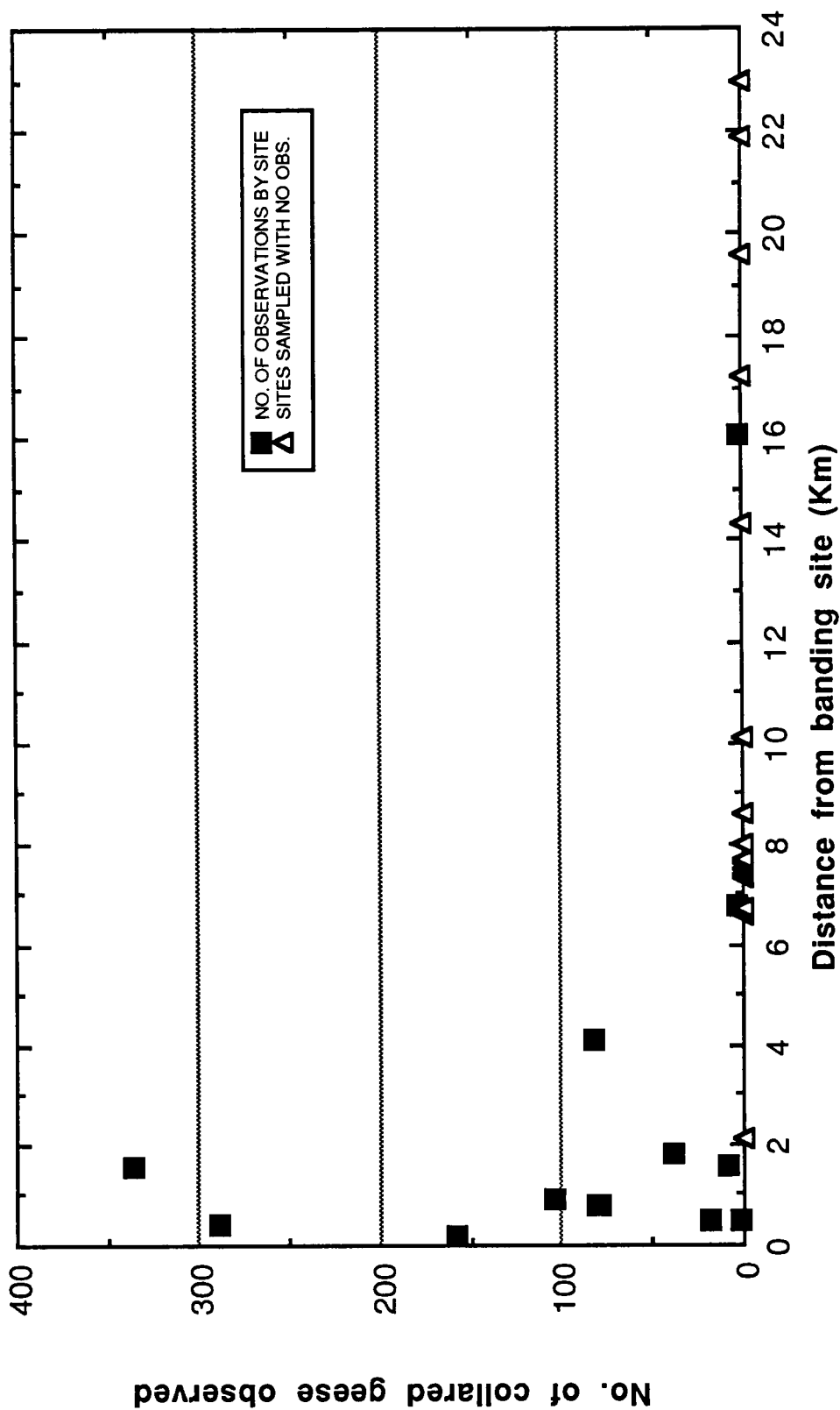


Figure 14. Dispersal of geese collared at ORGDP from 6/23/89 to 4/6/90.

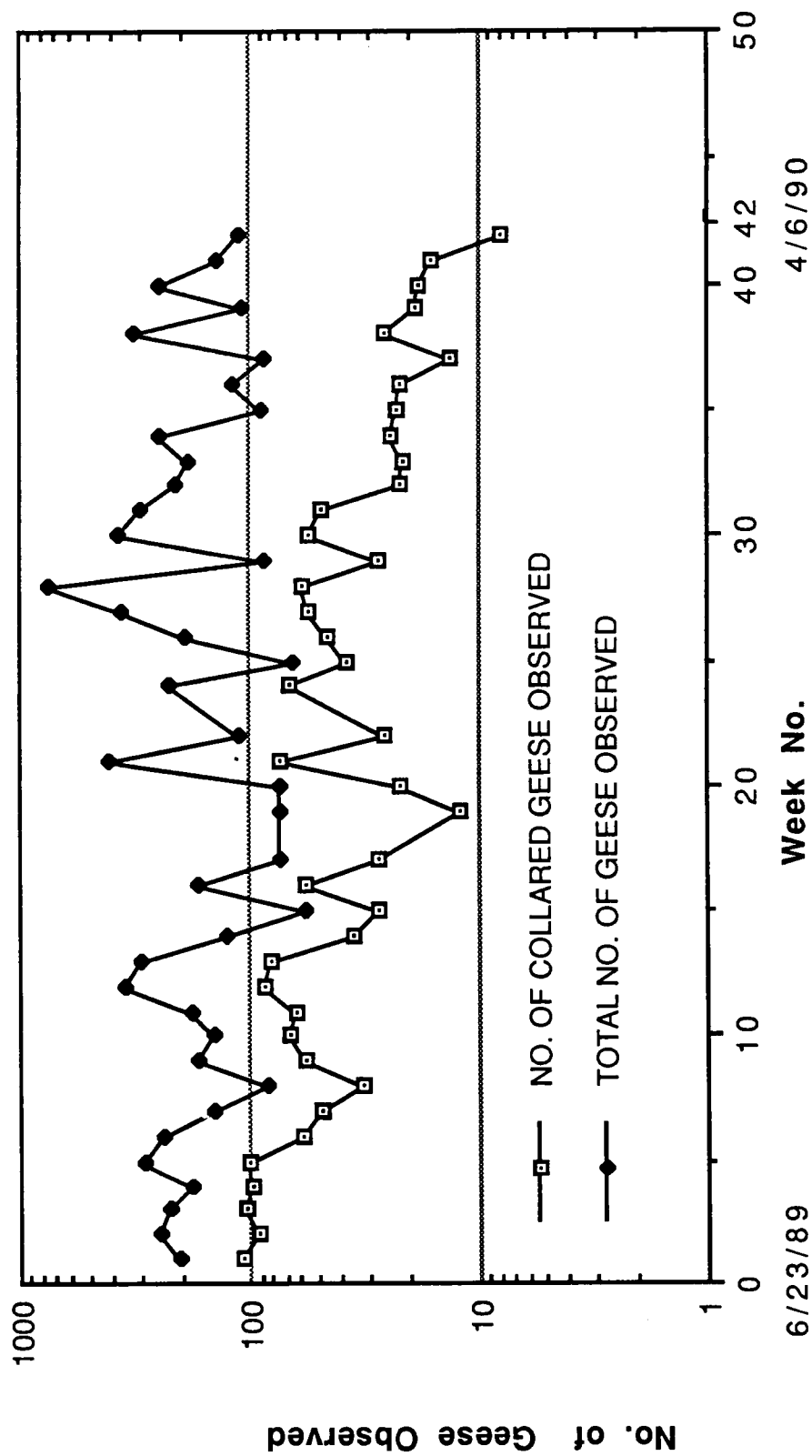


Figure 15. Number of Canada geese observed each week at all census sites.

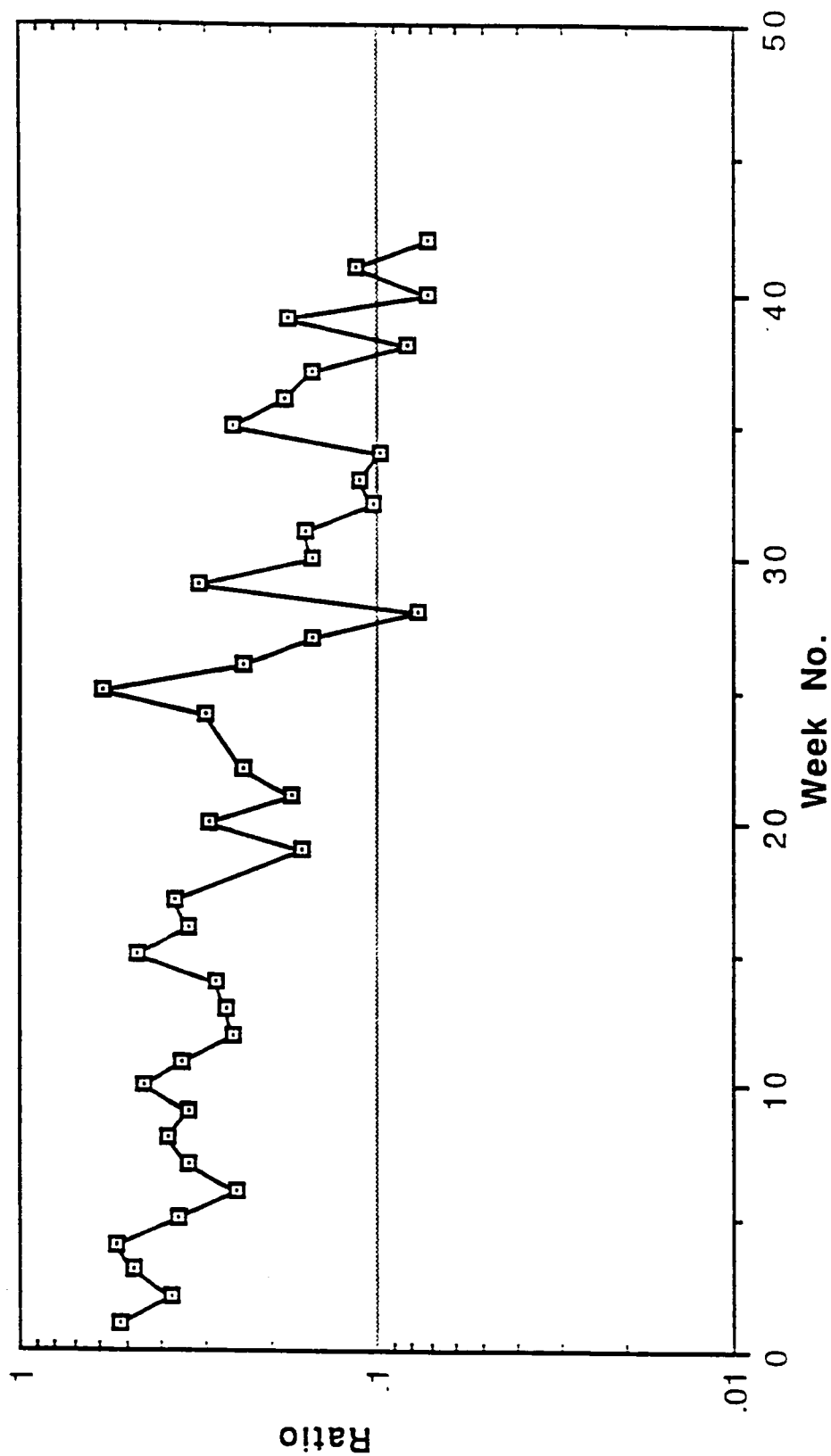


Figure 16. Ratio of total number of collared geese observed each week to the total number of geese observed at all census sites.

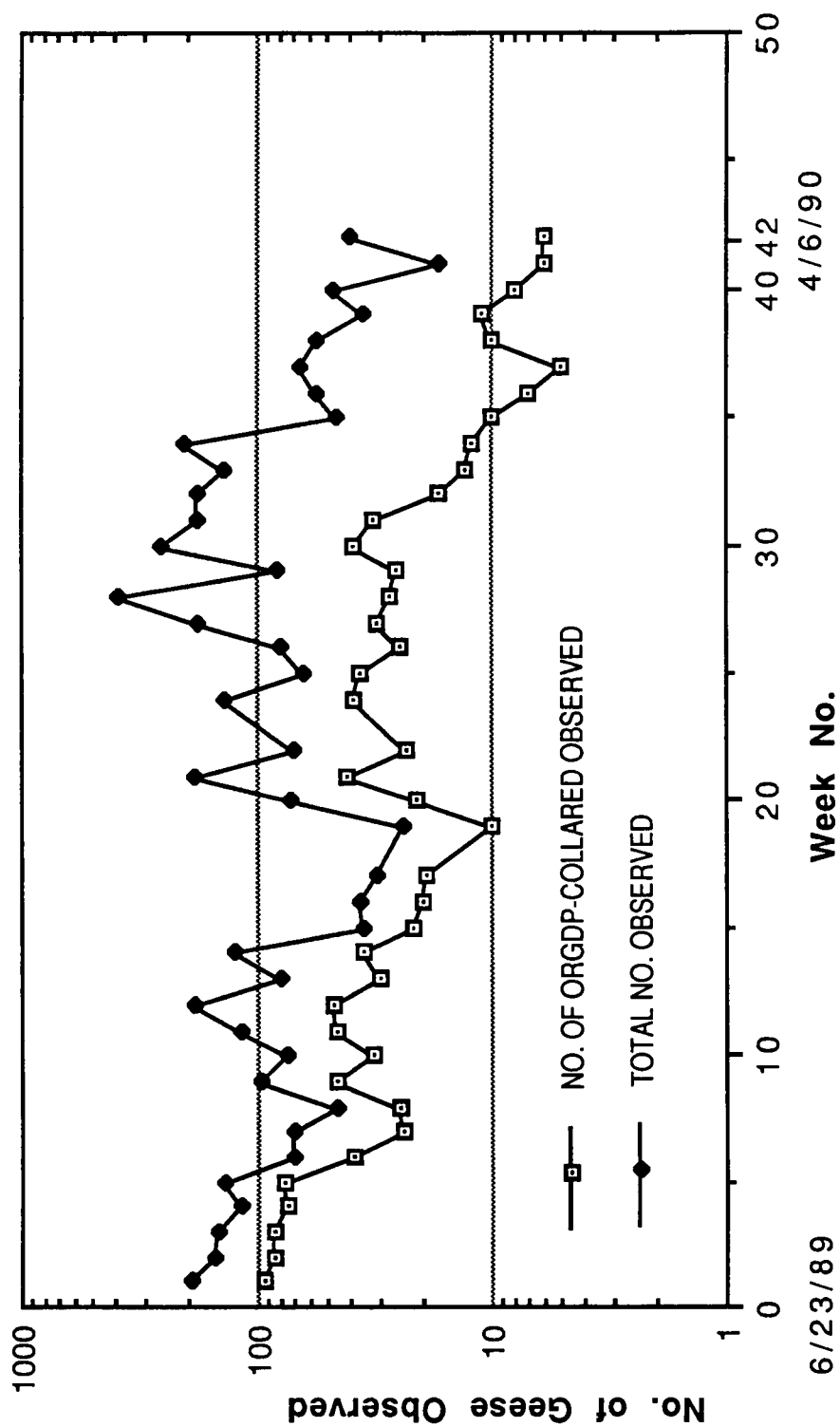


Figure 17. Number of geese observed at ORGDP each week.

during the weekly census periods was more variable than at ORGDP (Figure 18).

Although analyses were not conducted on the monthly census data, observations indicated that Canada geese collared on the ORR use public and private areas on the Clinch River and Melton Hill Reservoir. For example, geese collared at ORNL were observed at Melton Hill Dam and at other locations on Melton Hill Reservoir. Furthermore, geese from all banding sites were observed at least once at privately owned or public areas. Some of these areas are open to hunters, such as the Melton Hill Reservoir.

3.3. CONTAMINANTS IN WATERFOWL AND COOTS

3.3.1. CONTAMINANTS IN WILD WATERFOWL AND COOTS

Cesium-137 was the primary radionuclide detected in waterfowl collected from ORNL. Low levels of ^{60}Co were detected in some samples, mostly in whole body, gastrointestinal tract, and gizzard contents. Strontium-90 was detected in bone samples. The rank order of average ^{137}Cs concentrations for all wild waterfowl analyzed was in gizzard contents > gastrointestinal tract > whole body > breast tissue > feathers > bone > liver > kidney. Only road-killed geese were collected from ORGDP and the Y-12 Plant. The metals detected in waterfowl collected at the ORR include silver, cadmium, mercury, lead, and selenium. Arsenic was below minimum detectable limits ($<0.3 \mu\text{g/g}$) in all samples analyzed. Lead concentrations were generally below detectable limits ($<0.1 \mu\text{g/g}$) in most samples, but some contained 0.2 to $33 \mu\text{g/g}$ of lead. Silver concentrations

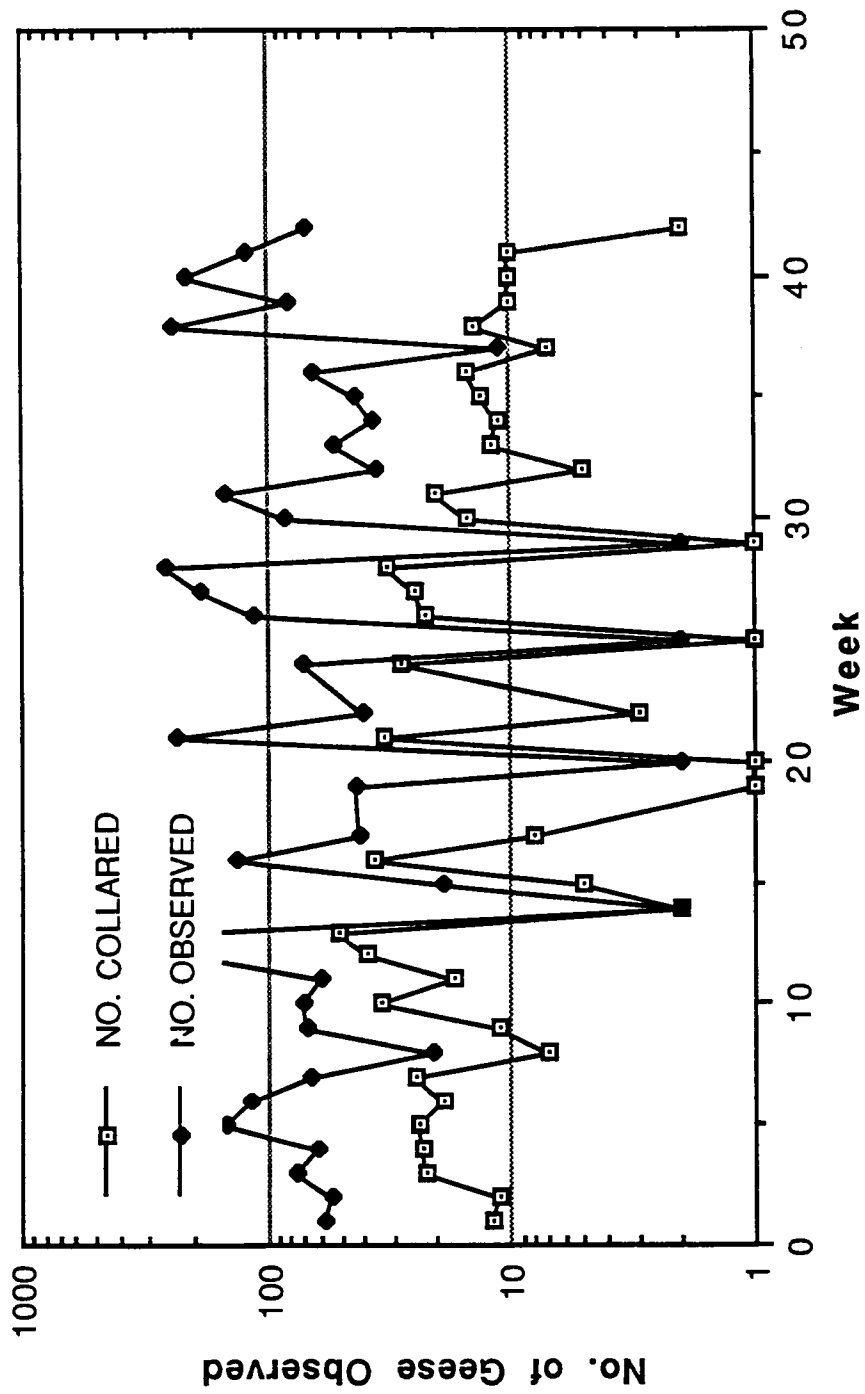


Figure 18. Observations of Canada geese collared at sites other than ORGDP.

were also below minimum detectable limits ($<0.2 \mu\text{g/g}$) except for one wood duck that contained $1.3 \mu\text{g/g}$ in liver. Detection limits for cadmium, mercury, and selenium were <0.05 , <0.001 , and $<0.3 \mu\text{g/g}$, respectively.

3.3.1.1. Migratory Waterfowl and Coots

The transient or migratory waterfowl collected from WOL consisted of seven mallards in 1987; five gadwalls, two mallards, and one black duck during winter 1988-89; and five black ducks and one mallard in winter 1989-90. Three coots were also sampled from WOL in 1988 and analyses were reported separately from the dabbling ducks. Although coots are members of the family Rallidae, they generally share the same habitat with some waterfowl species.

Cesium-137, cadmium, mercury, and selenium concentrations in breast tissue and ^{90}Sr in bone for gadwalls, mallards, and black ducks were partitioned by species and year of collection in Table 2. The rank order of mean concentrations of ^{137}Cs for all dabbling ducks was in gizzard contents $>$ gastrointestinal tract $>$ whole body $>$ feathers $>$ breast tissue $>$ liver $>$ bone $>$ kidney. The concentrations of ^{60}Co that were detected in several breast tissue, liver, kidney, and feather samples did not exceed 80 Bq/kg (2.2 pCi/g) but were generally $\leq 37 \text{ Bq/kg}$ ($\leq 1 \text{ pCi/g}$). Cobalt-60 levels in gizzard contents and gastrointestinal tract did not exceed 940 Bq/kg (25 pCi/g) but were generally much lower.

A significant difference was determined in ^{90}Sr concentrations among gadwalls, mallards, and black duck sampled in 1988-89 ($p = 0.004$) and between black ducks sampled in 1988-89 and 1989-90 ($p = 0.009$).

Table 2. Mean radionuclide (Bq/kg) and metal ($\mu\text{g/g}$) concentrations in WOL migratory waterfowl partitioned by species and year of collection.

Contaminant in Tissue	1987 Mean $\pm$ S.E. Range	1988-89 Mean $\pm$ S.E. Range	1989-90 Mean $\pm$ S.E. Range
Black Duck	n=0	n=1	n=5
Csb ^a		238	135 $\pm$ 42 53 - 283
Cdb ^b		0.03	N.D. ^f
Hgb ^c		0.08	N.D.
Seb ^d		0.40	N.D.
Srb ^e		530	190 $\pm$ 45 61 - 320
Gadwall	n=0	n=5	n=0
Csb		230 $\pm$ 33 151 - 340	
Cdb		0.021 $\pm$ 0.01 0.005 - 0.07	
Hgb		0.014 $\pm$ 0.004 0.009 - 0.03	
Seb		0.64 $\pm$ 0.07 0.5 - 0.9	
Srb		104 $\pm$ 33 44 - 220	

Table 2. (continued).

Contaminant in Tissue	1987 Mean $\pm$ S.E. Range	1988-89 Mean $\pm$ S.E. Range	1989-90 Mean $\pm$ S.E. Range
Mallard	n=7	n=2	n=1
Csb	141 $\pm$ 27 31 - 211	244 $\pm$ 14 230 - 257	41
Cdb	N.D.	0.32 $\pm$ 0.32 0.05 - 0.64	N.D.
Hgb	N.D.	0.02 $\pm$ 0.01 0.009 - 0.03	N.D.
Seb	N.D.	0.70 $\pm$ 0.01 0.60 - 0.80	N.D.
Srb	585 $\pm$ 500 27 - 2600 (n=5)	150 $\pm$ 50 100 -200	200

^aCsb = ¹³⁷Cs in breast tissue.

^bCdb = Cadmium in breast tissue.

^cHgb = Mercury in breast tissue.

^dSeb = Selenium in breast tissue.

^eSrb = ⁹⁰Sr in bone.

^fN.D. = Not Determined.

Mercury concentrations in breast tissue were also significantly different among species sampled in 1988-89 ($p = 0.037$). Cesium-137 concentrations in breast tissue for the black duck, gadwalls, and mallards combined averaged 270 Bq/kg (7.3 pCi/g) with a range of 31 Bq/kg (0.85 pCi/g) to 340 Bq/kg (9.2 pCi/g). The mean mercury and selenium concentrations in kidney were 0.11 $\mu\text{g/g}$ (0.031 to 0.32 $\mu\text{g/g}$) and 1.8 $\mu\text{g/g}$ (1.5 to 2.1 $\mu\text{g/g}$), respectively. Cadmium concentrations averaged 0.10 $\mu\text{g/g}$ (0.005 to 0.64 $\mu\text{g/g}$) in breast tissue and 5.88 $\mu\text{g/g}$ (0.54 to 13.2 $\mu\text{g/g}$) in kidney.

The three American coots collected from WOL were assessed separately from the dabbling ducks. Tissues from these birds were not analyzed for metals. The coots accumulated higher concentrations of ^{137}Cs in tissues in comparison to waterfowl collected from WOL. Cesium-137 in whole body averaged 1460 Bq/kg (40 pCi/g), and breast tissue contained a mean of 630 Bq/kg (17 pCi/g) (Table 3). Strontium-90 averaged 190 Bq/kg (5.1 pCi/g) in bone. These coots were believed to be on WOL for approximately three months before they were collected because a small flock of coots was censused on WOL during this period.

3.3.1.2. WOL Wood Ducks

The rank order of mean ^{137}Cs concentrations for all wood ducks was in gizzard contents > gastrointestinal tract > whole body > kidney > breast tissue > feathers > bone > liver. Seven immature wood ducks collected from the WOL area in 1989 averaged 131 Bq/kg (3.6 pCi/g) of ^{137}Cs in breast tissue with a range of 21 Bq/kg (0.57 pCi/g) to 272 Bq/kg

Table 3. Mean ^{137}Cs and ^{60}Co concentrations (Bq/kg) in WOL coots.

Organ/Tissue n = 3	Mean $\pm$ S.E. ^{137}Cs	Range ^{137}Cs	Mean $\pm$ S.E. ^{60}Co	Range ^{60}Co
Whole Body	1460 $\pm$ 125	1260-1690	120 $\pm$ 17	96-155
Breast tissue	630 $\pm$ 65	525-750	N.D. ^a	N.D.
Liver	350 $\pm$ 32	315-730	55 $\pm$ 4.5	48-63
Gastrointestinal Tract	3020 $\pm$ 1360	1020-5600	310 $\pm$ 132	85-540
Gizzard	1080 $\pm$ 288	685-1630	100 $\pm$ 38	44-170
Gizzard Contents	6560 $\pm$ 1000	4990-8420	670 $\pm$ 91	544-850
Bone ^b	360 $\pm$ 29	307-400	N.D.	N.D.
Carcass	540 $\pm$ 85	422-700	20 $\pm$ 4.6	15-30

^aN.D. = Not detectable

^bMean ^{90}Sr concentration in bone was 190 $\pm$ 15 Bq/kg.

(7.4 pCi/g). Three adult wood ducks were collected from WOL in 1989. Cesium-137 concentrations detected in the adult wood ducks collected from the lake area averaged 131 Bq/kg (3.6 pCi/g) in breast tissue with a range of 109 Bq/kg (2.9 pCi/g) to 163 Bq/kg (4.4 pCi/g). No significant differences were determined between immature and adult wood ducks for ^{137}Cs concentrations in breast tissue, liver, and kidney and ^{90}Sr concentrations in bone (Table 4). One of these adult wood ducks was collected from White Oak Creek Weir (WOCW) and contained 5570 Bq/kg (150 pCi/g) of ^{60}Co in whole body but only 81 Bq/kg (2.2 pCi/g) in breast tissue. Melton Branch Weir, which is located several hundred yards from WOCW, is known to contain higher levels of ^{60}Co ; therefore, the bird probably had been using this area before it was collected.

Mercury concentrations in breast, liver, and kidney tissues of immature birds averaged 0.04 $\mu\text{g/g}$, 0.09 $\mu\text{g/g}$, and 0.13 $\mu\text{g/g}$, respectively. In comparison, adults averaged 0.06 $\mu\text{g/g}$, 0.25 $\mu\text{g/g}$, and 0.38 $\mu\text{g/g}$ of mercury in breast, liver, and kidney tissues, respectively. Mercury concentrations were not significantly different between the immature and adult wood ducks. Mean cadmium and selenium concentrations were not statistically different between the adults and the immature ducks, except for cadmium in kidney and selenium in breast tissue (Table 5). Significant heterogeneity of variance was determined in several responses.

3.3.1.3. Canada Geese

The ^{137}Cs concentrations detected in a pair of Canada geese collected from Basin 3524 in March 1989 were the highest levels detected in

Table 4. Mean ^{137}Cs and ^{90}Sr concentrations (Bq/kg) in wood ducks collected from WOL.^a

Sample Description	Mean $\pm$ S.E. ^{137}Cs	Range ^{137}Cs	Mean $\pm$ S.E. ^{90}Sr	Range ^{90}Sr
Immatures				
n = 7				
Whole body	376 $\pm$ 109	39 - 936		
Breast tissue	131 $\pm$ 34	21 - 272		
Liver	81 $\pm$ 20	13 - 164		
Kidney	148 $\pm$ 31	47 - 253		
Bone	103 $\pm$ 27	15 - 202	6630 $\pm$ 3620	130 - 27,000
GI Tract+Gizzard	572 $\pm$ 377	32 - 3110		
Gizzard Contents	890 $\pm$ 570	7.0 - 4740		
Feathers (n = 5)	124 $\pm$ 28	16 - 181		
Adults				
n = 3				
Whole body	203 $\pm$ 9	190 - 219		
Breast tissue	131 $\pm$ 16	109 - 163		
Liver	72 $\pm$ 16	1.0 - 100		
Kidney	129 $\pm$ 33	82 - 192		
Bone	89 $\pm$ 31	53 - 151	950 $\pm$ 825	120 - 2600
GI Tract+Gizzard	143 $\pm$ 60	78 - 263		
Gizzard Contents	165 $\pm$ 67	48 - 281		
p values				
Breast tissue	0.99			
Liver	0.72			
Kidney	0.68			
Bone			0.17 ^b	

^aLow levels of ^{60}Co not included in table.

^bSignificant heterogeneity of variance ($p < 0.05$), Satterthwaites approximation used.

Table 5. Mean and range of cadmium, mercury, and selenium concentrations ($\mu\text{g/g}$) in wood ducks collected from WOL.

Sample Description	Mean $\pm$ S.E. Cd	Range Cd	Mean $\pm$ S.E. Hg	Range Hg	Mean $\pm$ S.E. Se	Range Se
Immatures n = 7						
Breast tissue	0.09 $\pm$ 0.05	0.01 - 0.35	0.04 $\pm$ 0.006	0.008-0.09	0.64 $\pm$ 0.09	0.30 - 0.90
Liver	0.52 $\pm$ 0.31	0.07 - 2.30	0.09 $\pm$ 0.02	0.03-0.14	2.5 $\pm$ 0.59	1.0 - 5.7
Kidney	2.6 $\pm$ 1.7	0.08 - 12	0.13 $\pm$ 0.02	0.04-0.19	1.5 $\pm$ 0.21	0.80 - 2.3
Adults n = 3						
Breast tissue	0.02 $\pm$ 0.01	0.01 - 0.03	0.06 $\pm$ 0.03	0.008-0.09	1.2 $\pm$ 0.09	1.1 - 1.3
Liver	1.5 $\pm$ 0.42	0.93 - 2.3	0.25 $\pm$ 0.12	0.038-0.45	2.5 $\pm$ 0.39	2.0 - 3.3
Kidney	13.1 $\pm$ 2.6	7.8 - 16	0.38 $\pm$ 0.20	0.053-0.74	2.3 $\pm$ 0.38	1.6 - 2.9
p Values						
Breast tissue	0.18 ^a		0.55 ^a		0.003	
Liver	0.13		0.31 ^a		0.99	
Kidney	0.03		0.34 ^a		0.17	

^aSignificant heterogeneity of variance ($p < 0.05$), Satterthwaite's approximation used.

any waterfowl collected from the ORR. Although the geese only used the pond area for approximately one month (Jay Story, ORNL, personal communication), 146,000 (3950 pCi/g) and 106,000 Bq/kg (2860 pCi/g) of ^{137}Cs were determined in breast tissue (Table 6). Strontium-90 concentrations in bone averaged 24,000 Bq/kg (650 pCi/g). Cobalt-60, ^{152}Eu , ^{154}Eu , and ^{241}Am also were detected in gizzard contents, and ^{60}Co in liver samples.

Five ORNL Canada geese collected during the banding operation in 1988 contained ^{137}Cs above detectable levels. Mean breast tissue concentrations were 1190 Bq/kg (32.1 pCi/g) with a range of 760 to 1750 Bq/kg (21 to 47 pCi/g). Liver concentrations peaked at 730 Bq/kg (20 pCi/g) with an average of 630 Bq/kg (17 pCi/g). Mercury levels in breast tissue averaged 0.005 $\mu\text{g/g}$ with a range of 0.002 to 0.008 $\mu\text{g/g}$. In liver, mean mercury levels were 0.028 $\mu\text{g/g}$ with a range of 0.010 to 0.066 $\mu\text{g/g}$. Mean selenium concentrations were <3 $\mu\text{g/g}$ in breast tissue and 0.86 $\mu\text{g/g}$ (0.6 to 1.4 $\mu\text{g/g}$) in liver (Table A-1). Cadmium residues were below detectable limits in breast tissue (<0.05 $\mu\text{g/g}$) and ranged from <0.05 to 0.60 $\mu\text{g/g}$ in liver.

The six Canada geese collected in July 1989 near the ORNL sewage ponds contained a mean concentration of 101 Bq/kg (2.7 pCi/g) of ^{137}Cs in breast tissue with a range of 40 to 163 Bq/kg (0.97 to 4.4 pCi/g). Strontium-90 concentrations in four bone samples averaged 2250 Bq/kg (61 pCi/g). The geese must have accumulated these radionuclide levels within one month considering that they were analyzed for radioactivity when they were banded in June 1989, and the levels were not significantly above background at that time. Mercury concentrations in breast tissue, liver, and

Table 6. Cesium-137, ^{60}Co , and ^{90}Sr concentrations (Bq/kg) in tissues of Basin 3524 Canada geese.

Goose Identification	Organ/Tissue	^{137}Cs	^{60}Co	^{90}Sr
1	Breast Tissue	146,000	17	
	Liver	15,000	160	
	Gizzard Contents	55,000	2300	
	Bone	21,000	80	3600
2	Breast Tissue	106,000	N.D. ^a	
	Liver	24,000	160	
	Gizzard Contents	66,000	3400	
	Bone	27,000	N.D.	40,000

^aN.D. = Not detectable

kidney from three of the geese ranged from 0.001 to 0.003 µg/g, 0.017 to 0.036 µg/g, and 0.013 to 0.024 µg/g, respectively. Selenium concentrations in breast, liver, and kidney tissues ranged from <0.3 to 0.3 µg/g, 0.5 to 0.8 µg/g, and 0.4 to 0.7 µg/g, respectively. Cadmium levels in breast tissue, liver, and kidney ranged from <0.05 to 0.05, 0.61 to 11, and 0.16 to 1.8, respectively (Table A-1). These cadmium levels in liver are slightly higher than in the 1988 geese.

Cesium-137 and ⁶⁰Co concentrations in tissues from two Canada geese collected from WOL in 1989 did not exceed minimum detectable levels except in feathers which averaged 15 Bq/kg (0.41 pCi/g). Concentrations of man-made radionuclides in tissues from road-killed Canada geese were all below minimum detectable levels. Table A-2 shows the metal concentrations detected in ORR road-killed Canada geese. Concentrations were all fairly low.

3.3.1.4. Potential Dose to Humans

The potential effective dose commitment to humans was calculated using the maximum and average breast tissue concentrations of ¹³⁷Cs for the various groups of waterfowl collected from ORNL. The basic dose limit for radiation exposure to humans is 1 mSv/yr (100 mrem/yr) at the DOE facilities as recommended by Gilbert et al. (1985). The average weight of the transient gadwalls was 850 grams. If a person were to consume 298 grams (35 percent of mean total body weight) of a migratory gadwall collected from WOL that was contaminated with the maximum concentration of ¹³⁷Cs in breast tissue (340 Bq/kg), the potential effective dose commitment would be 1.4 µSv (0.14 mrem). In comparison, the potential

effective dose commitment to a person from the consumption of 1600 grams of breast tissue from the Basin 3524 goose contaminated with the maximum ^{137}Cs concentrations would be 3.1 mSv (312 mrem) (Table 7). The potential effective dose commitment to humans from consumption of ^{60}Co contaminated breast tissue (81 Bq/kg) from a wood duck collected from WOL would be 0.17 μSv (0.017 mrem).

3.3.2. WOL Domestic Mallard Experiment

The survival of the domestic mallards released on WOL proved more successful for the second group of ducks than for the first group. More than half of the ducks from Group 1 could not be accounted for, but 30 of 40 birds (75%) were accounted for in Group 2. In Group 1 the high mortality rate was probably due to predation because the remains of several mallards were found in the lake area. No birds remained on WOL after day 77 in Group 1 and day 95 in Group 2. Elimination rates could not be determined because too few birds survived to the end of the experiment.

Cesium-137 was the primary radionuclide detected in all mallard tissues. Low levels of ^{60}Co were also determined in several whole-body, gastrointestinal tract, gizzard contents, and liver samples. The ^{137}Cs concentration in breast tissue from the Group 1 mallards increased from below detectable levels (N.D.) on day 2 to 354 Bq/kg (9.6 pCi/g) on day 77 (Table 8). Mean ^{137}Cs concentrations in tissue from Group 2 mallards increased from 5.2 Bq/kg (0.14 pCi/g) on day 2 to 277 Bq/kg (7.5 pCi/g) on day 61. Peak ^{137}Cs concentrations were detected in ducks collected during the latter sampling periods for each group.

Table 7. Potential dose to humans from the consumption of ^{137}Cs contaminated breast tissue from waterfowl or coots collected on the ORR.

Waterfowl Identification	Sampling Location		Grams Consumed ^a	^{137}Cs (Bq/kg)	Dose (μSv) ^b
Migratory Dabbler Duck ^c Gadwall	WOL	mean	380	270	0.87
		max	298	340	1.4
Coot	WOL	mean	256	625	2.2
		max	256	750	2.6
Wood Duck	WOL	mean	194	131	0.35
		max	194	272	0.72
Canada Goose	Basin 3524	mean	1600	125,000	2700
		max	1600	146,000	3120
Canada Goose (1988)	ORNL	mean	1600	1190	25.7
		max	1600	1750	37.8
Canada Goose (1989)	ORNL	mean	1600	100	2.2
		max	1600	160	3.5

^aAmount of tissue consumed is based on 35 percent of mean total body weight for each species.

^b $\mu\text{Sv} = 0.1 \text{ mrem}$

^cMigratory dabbler ducks include black ducks, gadwalls, and mallards.

Table 8. Cesium-137 and ⁹⁰Sr concentrations (Bq/kg) in tissues/organs from WOL domestic mallards.^a

Elapsed Time (days)	Tissue/ Organ (Sample Size)	Mean ± S.E. ¹³⁷ Cs	Mean S.E. ⁹⁰ Sr	
Group 1				
0	Whole body(2)	N.D. ^b		
	Breast tissue	N.D.		
	Liver	N.D.		
	Kidney	N.D.		
	GI tract		N.D.	
	Bone	N.D.	16	
2	Whole body(1)	20		
	Breast tissue	N.D.		
	Liver	4.9		
	Kidney	12		
	GI tract		8.3	
	Bone	N.D.	26	
4	Whole body(1)	42		
	Breast tissue	6.2		
	Liver	11		
	Kidney	14		
	GI tract		80	40
	Bone	N.D.		
9	Whole body(3)	157 ± 15		
	Breast tissue	45 ± 5.6		
	Liver	104 ± 1.3		
	Kidney	32 ± 22		
	GI tract		24 ± 72	
	Bone	29 ± 8.0	86 ± 6.9	
21	Whole body(3)	254 ± 18		
	Breast tissue	131 ± 33		
	Liver	124 ± 23		
	Kidney	40 ± 14		
	GI tract		250 ± 27	
	Bone	45 ± 6.92	170 ± 0	
49	Whole body(1)	217		
	Breast tissue	196		
	Liver	93		
	Kidney	159		
	GI tract		265	
	Bone	87	250	
77	Whole body(1)	407		
	Breast tissue	354		
	Liver	183		
	Kidney	315		
	GI tract		317	
	Bone	260	340	

Table 8. (continued).

Elapsed Time (days)	Tissue/ Organ (Sample Size)	Mean $\pm$ S.E. ^{137}Cs	Mean $\pm$ S.E. ^{90}Sr
Group 2			
0	Whole body(2)	N.D.	
	Breast tissue	N.D.	
	Liver	N.D.	
	Kidney	N.D.	
	GI tract		N.D.
	Bone	N.D.	16.5 $\pm$ 9.2
2	Whole body(4)	34 $\pm$ 9.0	
	Breast tissue	5.2 $\pm$ 1.1	
	Liver	20 $\pm$ 10	
	Kidney	20 $\pm$ 10	
	GI tract		73 $\pm$ 13
	Bone	5.6 $\pm$ 0.77	58 $\pm$ 13
4	Whole body(3)	52 $\pm$ 5.8	
	Breast tissue	22 $\pm$ 2.3	
	Liver	26 $\pm$ 4.0	
	Kidney	50 $\pm$ 16	
	GI tract		97 $\pm$ 20
	Bone	10 $\pm$ 0.035	78 $\pm$ 23
8	Whole body(3)	111 $\pm$ 3.9	
	Breast tissue	45 $\pm$ 1.7	
	Liver	29 $\pm$ 9.8	
	Kidney	60 $\pm$ 2.4	
	GI tract		73 $\pm$ 1.8
	Bone	24 $\pm$ 1.2	307 $\pm$ 38
16	Whole body(3)	163 $\pm$ 22	
	Breast tissue	73 $\pm$ 8.1	
	Liver	72 $\pm$ 1.0	
	Kidney	104 $\pm$ 3.7	
	GI tract		200 $\pm$ 20
	Bone	56 $\pm$ 3.0	583 $\pm$ 458
33	Whole body(1)	153	
	Breast tissue	151	
	Liver	116	
	Kidney	191	
	GI tract		184
	Bone	72	280
39	Whole body(3)	246 $\pm$ 22	
	Breast tissue	149 $\pm$ 11	
	Liver	118 $\pm$ 7.5	
	Kidney	165 $\pm$ 20	
	GI tract		323 $\pm$ 45
	Bone	63 $\pm$ 9.2	383 $\pm$ 73
61	Whole body(4)	420 $\pm$ 20	
	Breast tissue	277 $\pm$ 29	
	Liver	225 $\pm$ 13	
	Kidney	353 $\pm$ 25	
	GI tract		393 $\pm$ 24
	Bone	137 $\pm$ 11	678 $\pm$ 312

^aLow levels of ^{60}Co in tissues not included in table.^bN.D. = Not Detectable

The comparison of the concentration of ^{137}Cs in breast tissue over time was not significantly different for the two mallard groups ($F_{2,31} = 0.44$, $p > 0.25$). The scatter about the individual regression (lack-of-fit test) was not significant ($F_{10,23} = 0.90$, $p > 0.20$), indicating that the linear regression is an adequate model for ^{137}Cs uptake in breast tissue of the domestic WOL mallards. The linear regression was fit to the combined data shown in Figure 19. It is interesting to note that the concentration in breast tissue was still increasing after 60 to 90 days on WOL.

Although the concentrations of ^{137}Cs and ^{60}Co in whole body, and ^{137}Cs in liver did not differ statistically over time for the two mallard groups ($p > 0.10$), the linear model was adequate only for ^{60}Co concentrations ($F_{10,23} = 1.68$, $p > 0.10$) (Figure 20). Figures 21 and 22 show the increase of ^{137}Cs concentrations in whole body and liver as a function of time. Whole body ^{137}Cs concentrations were greater than liver concentrations.

Concentrations of ^{137}Cs in kidney over time differed significantly for the two mallard groups ($F_{2,31} = 4.4$, $p < 0.025$). A lack-of-fit test was applied to the data for each separate group. The linear model was adequate for each group separately (Group 1: $F_{5,5} = 4.8$, $p > 0.05$; Group 2: $F_{6,15} = 2.2$, $p > 0.05$) (Figure 23).

The ^{90}Sr uptake in bone was statistically different for the two mallard groups ($F_{2,31} = 7.0$, $p < 0.005$); therefore, a common regression was not calculated. A linear model was not adequate for Group 1 ($F_{5,5} = 13.7$, $p < 0.01$), but was for Group 2 ($F_{6,15} = 0.46$, $p > 0.25$). However, the Group 2 mallards included 6 immature ducks. The immature birds could accumulate higher concentrations of ^{90}Sr because they are still building bone mass and would concentrate more calcium or its antilog strontium. Therefore, based on

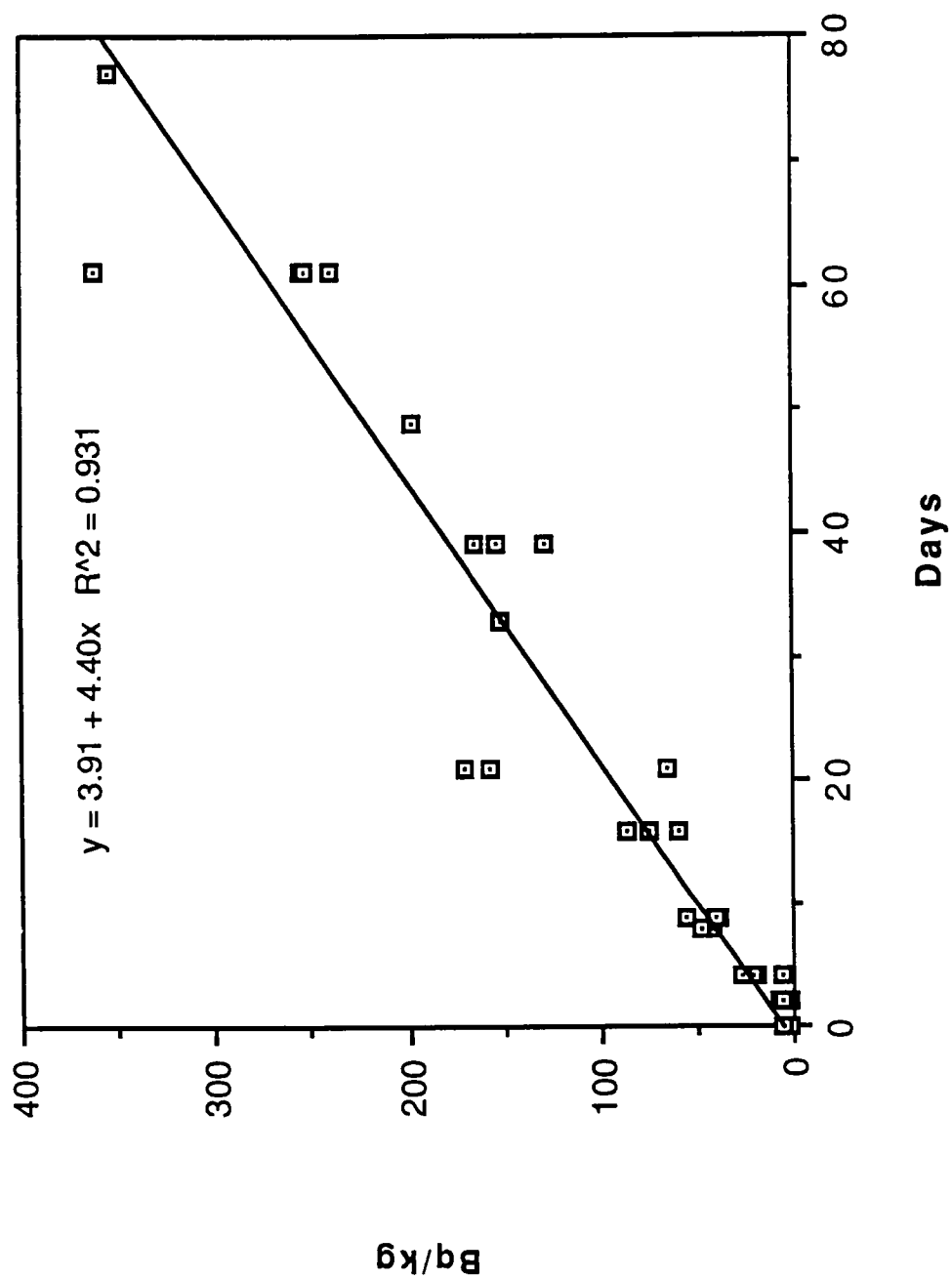
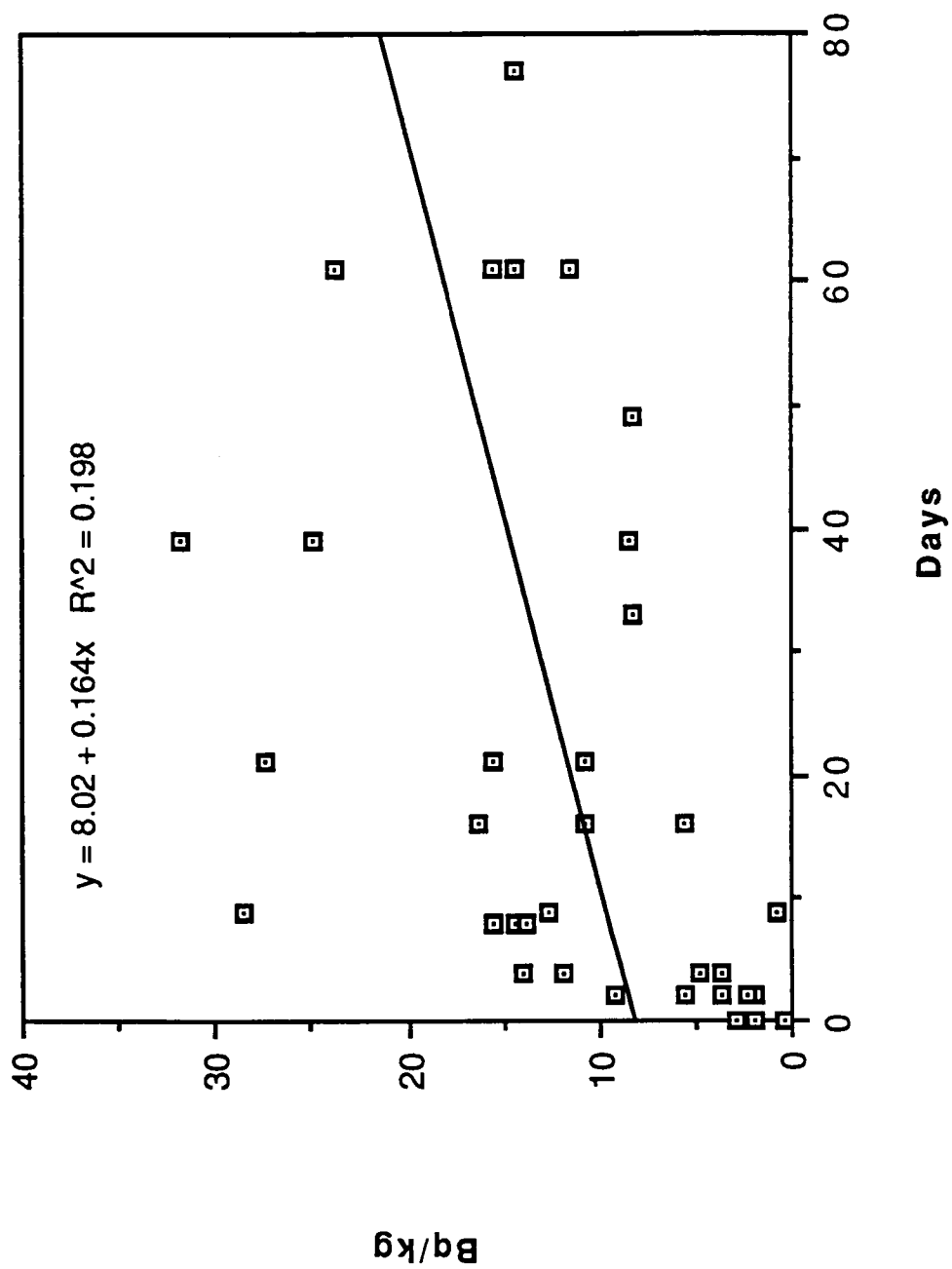


Figure 19. Uptake of ^{137}Cs in breast tissue from the combined data for the groups of domestic mallards released on WOL.



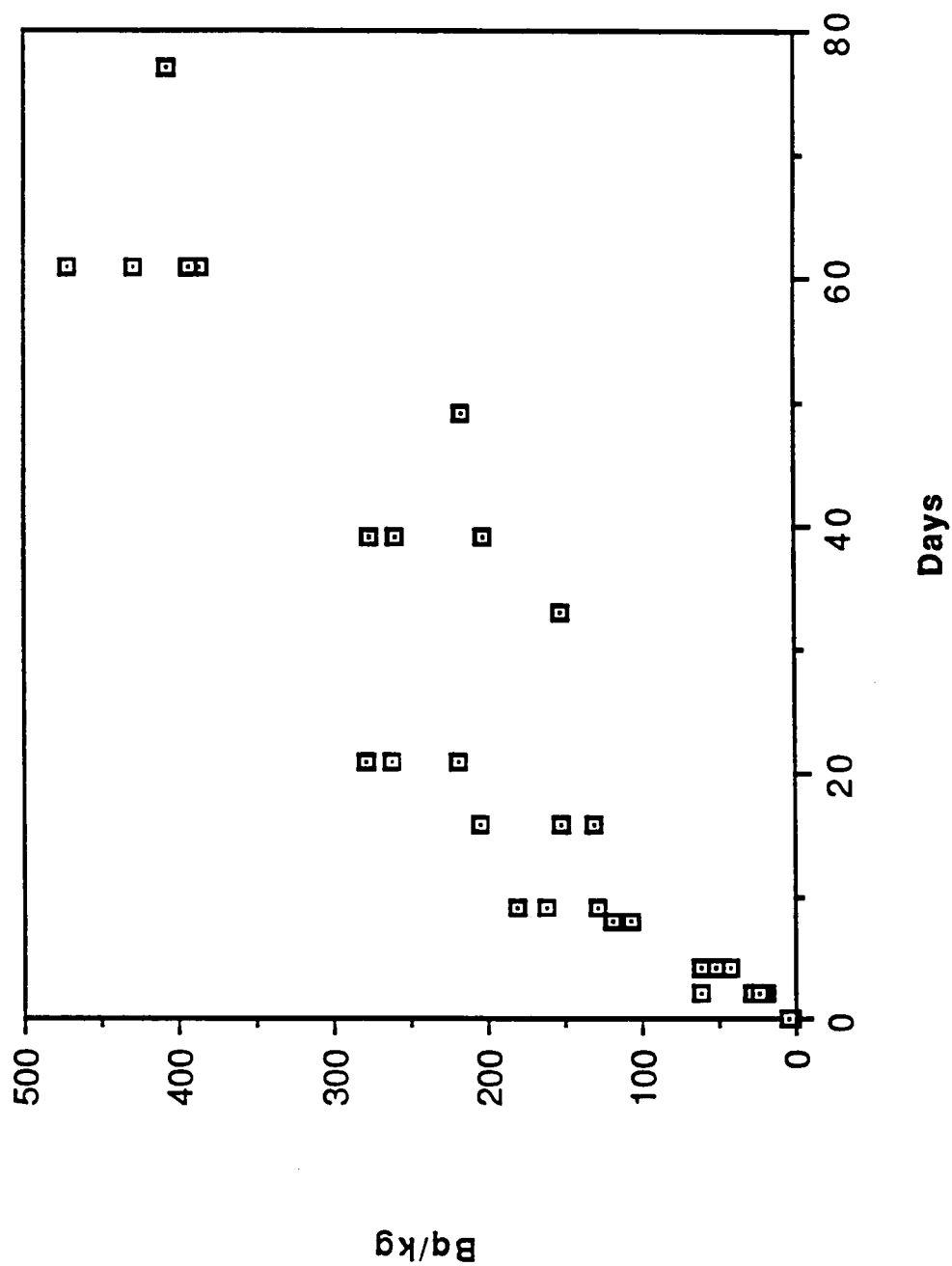


Figure 21. Cesium-137 concentrations in whole body for combined data from two groups of domestic mallards released on WOL. The linear model was not adequate for the data ($F_{10,23} = 11.7$, $p < 0.01$).

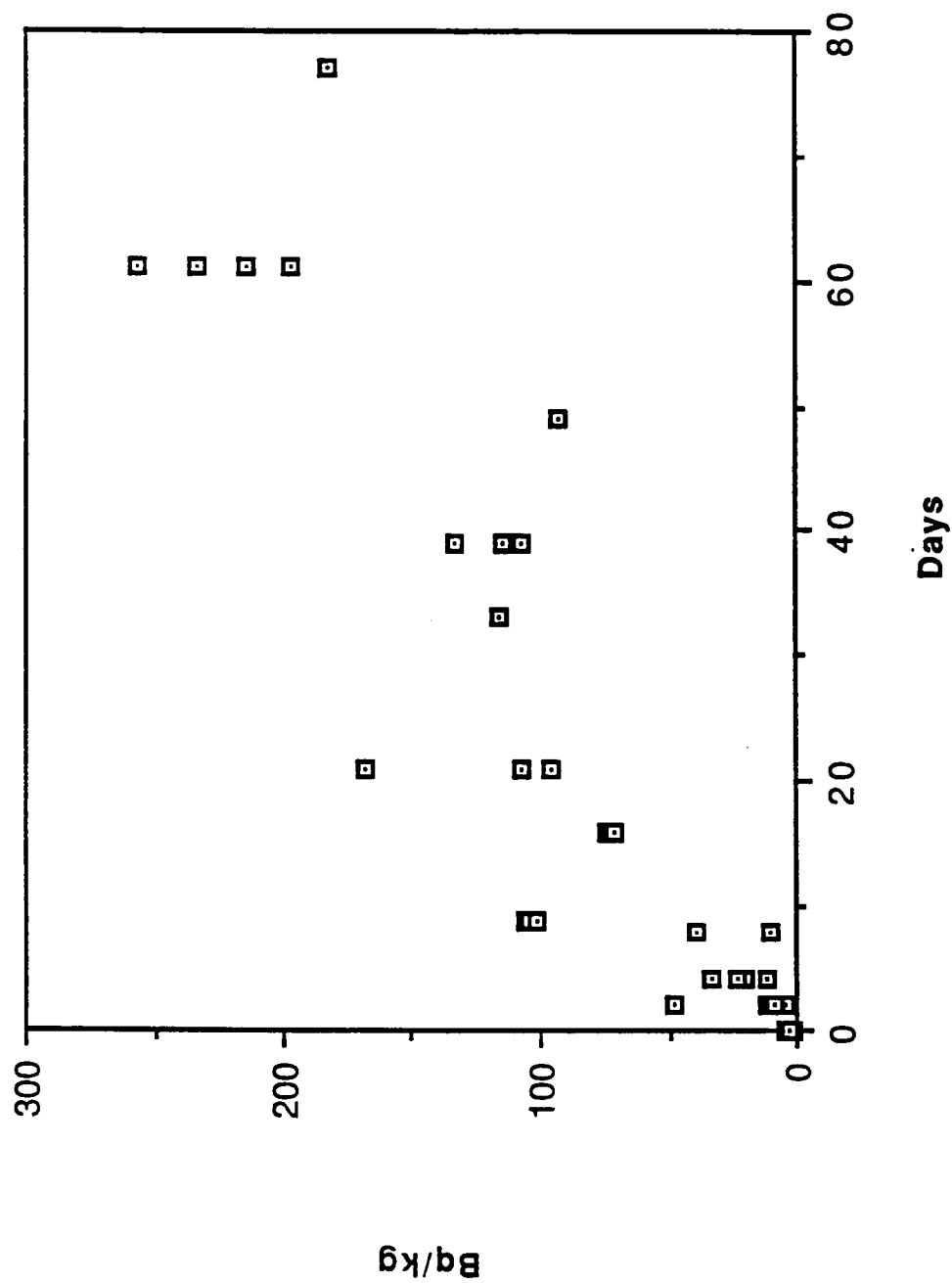


Figure 22. Cesium-137 concentrations in liver for the combined data from the two groups of domestic mallards released on WOL. The linear model was not adequate for the data ($F_{10,23} = 9.19$, $p < 0.01$).

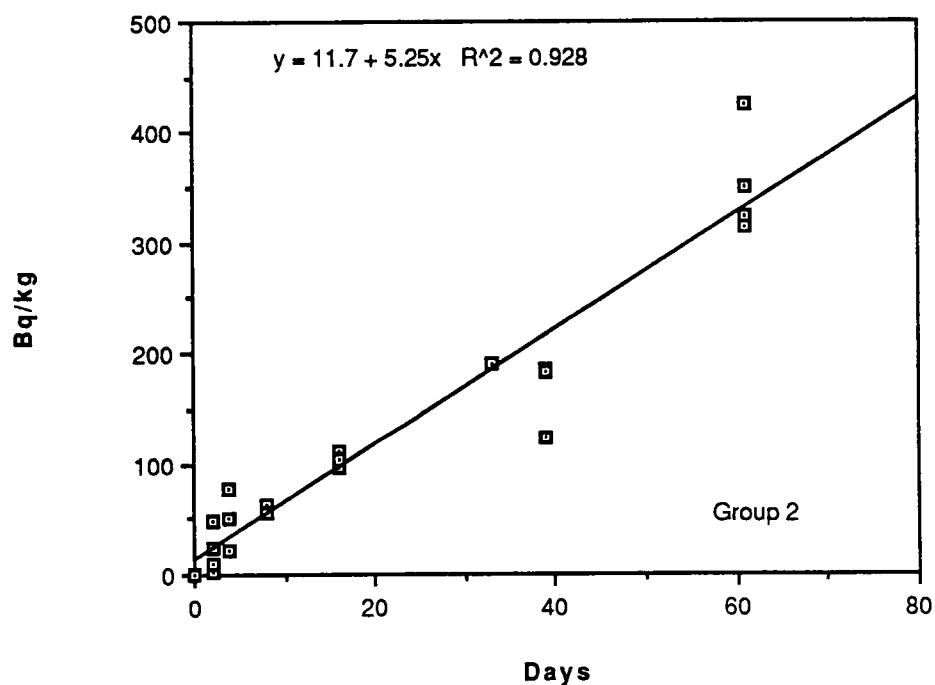
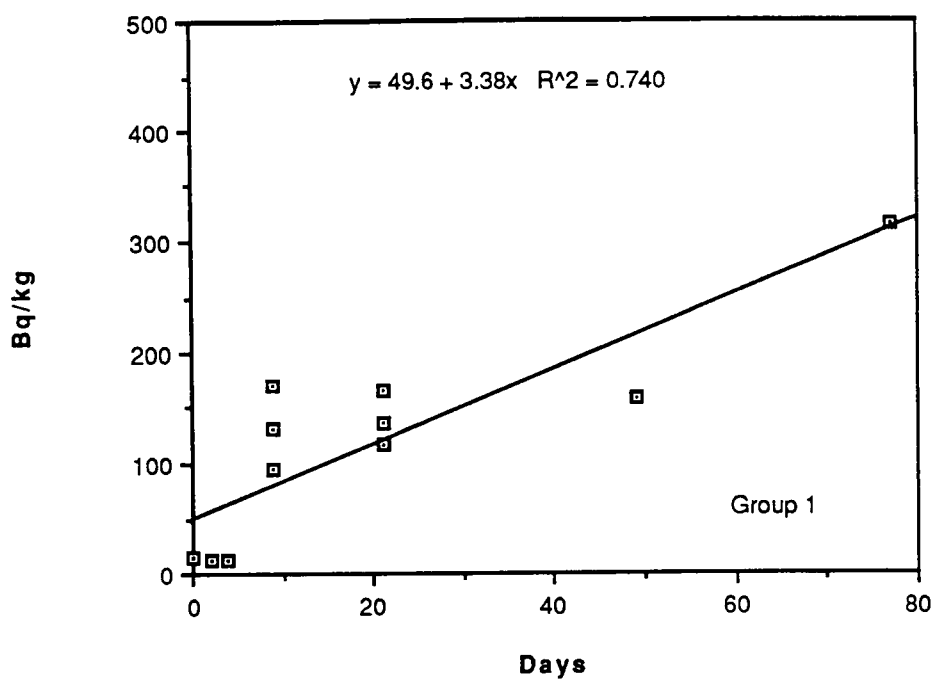


Figure 23. Cesium-137 uptake by kidney for each group of domestic mallards released on WOL.

this principle, these six values were removed and the equality of the regression lines re-evaluated. The accumulation of ^{90}Sr in bone then did not differ statistically for the two groups ($F_{2,25} = 3.04$, $p > 0.25$), and the data for the two groups were combined. The pooled data were adequately described by a linear regression model ($F_{9,18} = 2.14$, $p > 0.25$). Figure 24 shows the accumulation of ^{90}Sr in bone for the adults and the higher ^{90}Sr levels in bone of the immature mallards.

Analyses for metals in breast, liver, and kidney tissues from both groups of mallards detected cadmium, mercury, and selenium in these tissues and silver and lead in some samples (Table 9). Arsenic was below detection limits in all samples analyzed. Lead concentrations in tissues generally ranged between minimum detection limits and $1\text{ }\mu\text{g/g}$, except for 5 kidney samples which contained lead concentrations ranging from $3.2\text{ }\mu\text{g/g}$ to $240\text{ }\mu\text{g/g}$. Lead shot residue may have been inadvertently included in the tissue samples. Silver was first detected in mallards on day 9 for Group 1 and on day 16 for Group 2. Silver concentrations ranged from <0.2 to $2.4\text{ }\mu\text{g/g}$ in breast tissue, from <0.2 to $8.5\text{ }\mu\text{g/g}$ in liver, and from <0.2 to $0.8\text{ }\mu\text{g/g}$ in kidney. Mercury and selenium levels in tissues did not exceed $0.18\text{ }\mu\text{g/g}$ and $2.9\text{ }\mu\text{g/g}$, respectively. Cadmium, selenium, lead, and silver concentrations in mallard tissues were too variable to adequately present uptake data.

Mercury accumulation in breast tissue was statistically different for the two mallard groups ($F_{2,31} = 5.07$, $p < 0.025$). The linear model was adequate for Group 1 ($F_{5,5} = 3.6$, $p > 0.05$), but not for Group 2 ($F_{6,15} = 3.8$, $p < 0.01$). A lack-of-fit test for a quadratic model was applied to data from Group 2 and found not to be significant ($F_{6,15} = 0.29$, $p > 0.25$); therefore, the quadratic model was adequate for Group 2 (Figure 25).

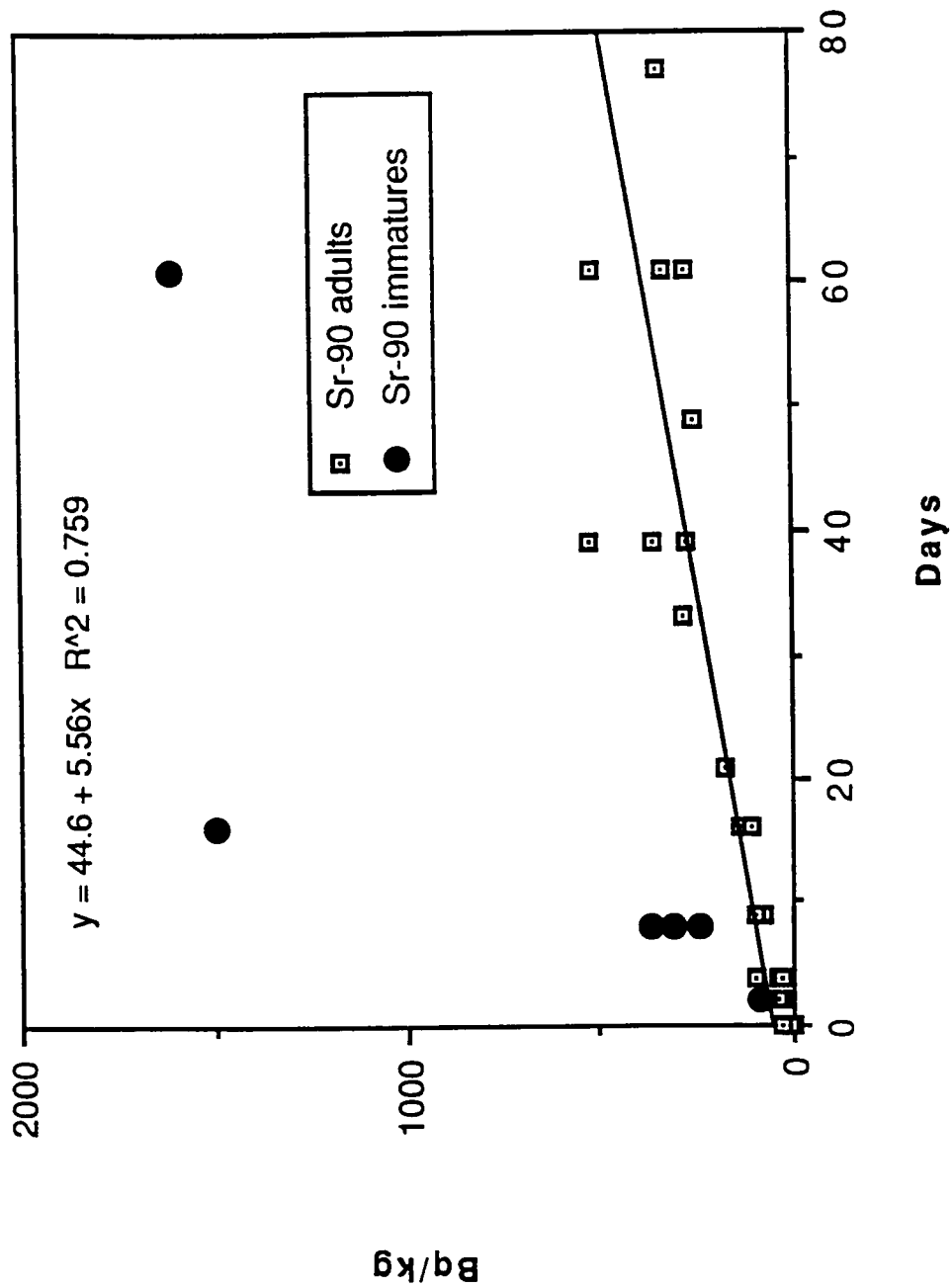


Figure 24. Strontium-90 uptake by bone from the WOL domestic mallards. A linear model is fit to ^{90}Sr concentrations in adult ducks only. Concentrations from the immature mallards were plotted separately.

Table 9. Cadmium, mercury, selenium, and silver concentrations ($\mu\text{g/g}$) in tissues/organs from WOL domestic mallards.

Elapsed Time Time (days)	Tissue/ Organ (Sample Size)	Cd	Mean $\pm$ S.E.		Ag
			Hg	Se	
Group 1					
0	Breast tissue(2)	0.06 $\pm$ 0	0.001 $\pm$ 0	0.45 $\pm$ 0.05	0.20 $\pm$ 0
	Liver	0.75 $\pm$ 1.8	0.001 $\pm$ 0	1.2 $\pm$ 0.20	0.20 $\pm$ 0
	Kidney	3.8 $\pm$ 1.8	0.001 $\pm$ 0	1.2 $\pm$ 0.15	0.20 $\pm$ 0
2	Breast tissue(1)	0.05	0.001	0.50	0.20
	Liver	2.1	0.001	1.8	0.20
	Kidney	4.1	0.002	1.4	0.20
4	Breast tissue(1)	0.05	0.001	0.30	0.20
	Liver	1.2	0.003	0.80	0.20
	Kidney	4.2	0.003	1.1	0.20
9	Breast tissue(3)	0.29 $\pm$ 0.28	0.004 $\pm$ 0	0.97 $\pm$ 0.57	0.50 $\pm$ 0.25
	Liver	0.99 $\pm$ 0.39	0.03 $\pm$ 0.005	1.8 $\pm$ 0.69	0.63 $\pm$ 0.23
	Kidney	3.2 $\pm$ 0.20	0.023 $\pm$ 0.005	1.2 $\pm$ 0.18	0.20 $\pm$ 0
21	Breast tissue(3)	0.03 $\pm$ 0.01	0.016 $\pm$ 0.002	0.97 $\pm$ 0.57	1.1 $\pm$ 0.66
	Liver	0.76 $\pm$ 0.38	0.063 $\pm$ 0.01	1.2 $\pm$ 0.24	2.4 $\pm$ 0.67
	Kidney	4.7 $\pm$ 4.1	0.038 $\pm$ 0.005	0.83 $\pm$ 0.35	0.20 $\pm$ 0
49	Breast tissue(1)	0.007	0.029	0.40	0.20
	Liver	1.5	0.24	1.8	4.6
	Kidney	4.2	0.14	1.7	0.30
77	Breast tissue(1)	0.03	0.045	0.30	0.20
	Liver	1.4	0.16	1.7	6.0
	Kidney	5.0	0.13	1.4	0.20

Table 9. (continued).

Elapsed Time Time (days)	Tissue/ Organ (Sample Size)	Cd	Mean $\pm$ S.E.		Ag
			Hg	Se	
Group 2					
0	Breast tissue(2)	0.22 $\pm$ 0.21	0.001 $\pm$ 0	0.45 $\pm$ 0.05	0.20 $\pm$ 0
	Liver	0.08 $\pm$ 0.04	0.001 $\pm$ 0	1.0 $\pm$ 0	0.20 $\pm$ 0
	Kidney	1.8 $\pm$ 1.5	0.001 $\pm$ 0	0.75 $\pm$ 0.15	0.20 $\pm$ 0
2	Breast tissue(4)	0.03 $\pm$ 0.01	0.002 $\pm$ 0.0001	0.45 $\pm$ 0.05	0.20 $\pm$ 0
	Liver	0.72 $\pm$ 0.25	0.002 $\pm$ 0.001	0.88 $\pm$ 0.09	0.20 $\pm$ 0
	Kidney	4.0 $\pm$ 2.0	0.002 $\pm$ 0.001	1.1 $\pm$ 0.05	0.20 $\pm$ 0
4	Breast tissue(3)	0.05 $\pm$ 0	0.002 $\pm$ 0	0.60 $\pm$ 0.30	0.20 $\pm$ 0
	Liver	1.2 $\pm$ 0.24	0.004 $\pm$ 0.001	1.1 $\pm$ 0.20	0.20 $\pm$ 0
	Kidney	3.8 $\pm$ 0.98	0.003 $\pm$ 0.001	1.1 $\pm$ 0.32	0.20 $\pm$ 0
8	Breast tissue(3)	0.09 $\pm$ 0.05	0.002 $\pm$ 0.001	0.37 $\pm$ 0.07	0.20 $\pm$ 0
	Liver	0.21 $\pm$ 0.02	0.02 $\pm$ 0.001	1.6 $\pm$ 0.12	0.20 $\pm$ 0
	Kidney	0.26 $\pm$ 0.10	0.009 $\pm$ 0.002	0.97 $\pm$ 0.14	0.20 $\pm$ 0
16	Breast tissue(3)	0.03 $\pm$ 0.07	0.005 $\pm$ 0.001	0.43 $\pm$ 0.04	0.20 $\pm$ 0
	Liver	0.31 $\pm$ 0.13	0.02 $\pm$ 0	1.2 $\pm$ 0.10	0.67 $\pm$ 0.20
	Kidney	1.8 $\pm$ 1.2	0.02 $\pm$ 0.003	0.63 $\pm$ 0.04	0.20 $\pm$ 0
33	Breast tissue(1)	0.05	0.021	0.30	0.20
	Liver	0.41	0.074	1.3	0.20
	Kidney	1.9	0.08	1.5	0.20
39	Breast tissue(3)	0.05 $\pm$ 0	0.024 $\pm$ 0.004	0.37 $\pm$ 0.12	0.20 $\pm$ 0
	Liver	0.52 $\pm$ 0.16	0.08 $\pm$ 0.02	1.7 $\pm$ 0.12	1.5 $\pm$ 0.23
	Kidney	1.4 $\pm$ 0.18	0.09 $\pm$ 0.02	1.2 $\pm$ 0.27	0.20 $\pm$ 0
61	Breast tissue(4)	0.13 $\pm$ 0.08	0.05 $\pm$ 0.004	0.4 $\pm$ 0	0.20 $\pm$ 0
	Liver	0.49 $\pm$ 0.13	0.16 $\pm$ 0.01	2.0 $\pm$ 0.28	5.4 $\pm$ 1.4
	Kidney	2.2 $\pm$ 0.65	0.14 $\pm$ 0.01	2.0 $\pm$ 0.21	0.73 $\pm$ 0.05

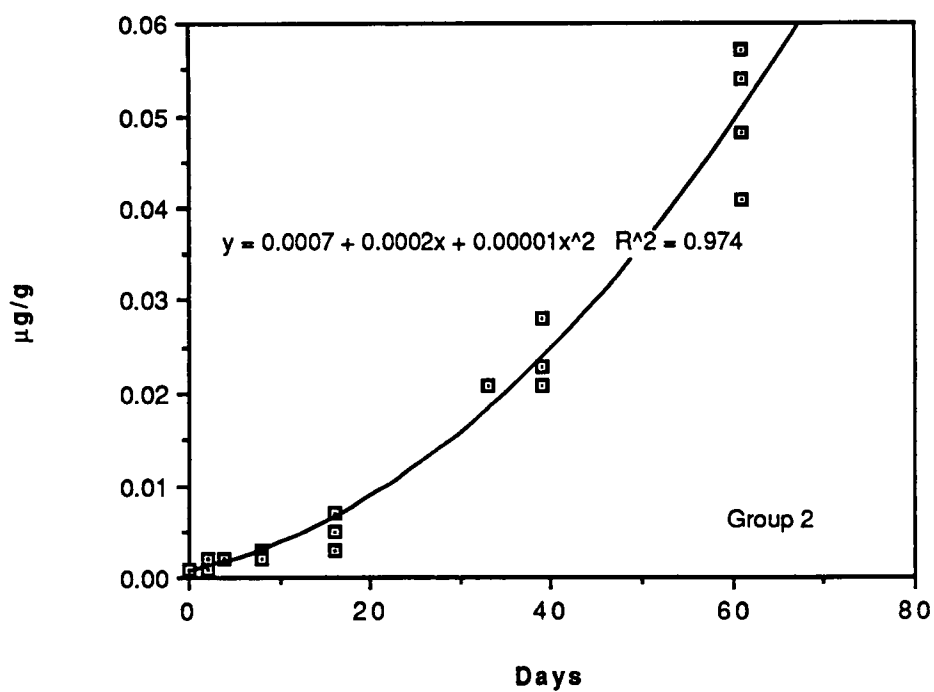
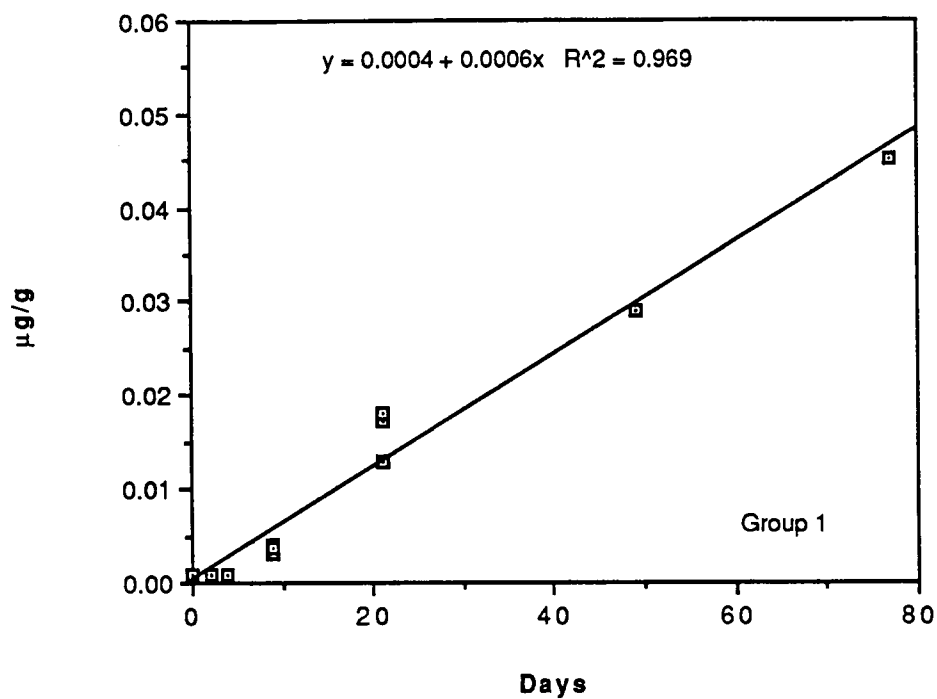


Figure 25. Mercury uptake by breast tissue in each group of domestic WOL mallards. A linear model was fit to Group 1 data and a quadratic model to Group 2.

Mercury accumulation over time relationship for liver and kidney did not differ statistically for the two mallard groups ($F_{2,31} = 2.06$, $p > 0.10$ and $F_{2,31} = 2.17$, $p > 0.25$, respectively), but the linear model was not adequate for the combined data. Because only a single duck was sampled on day 49 and day 77 in Group 1, these values could bias the statistical results. The mercury concentration in liver by day 49 in Group 1 was high in comparison to the other values for Group 1 and also to Group 2 mercury values in liver for similar time periods. The mercury concentrations in kidney on day 77 in Group 1 was low in comparison to the rest of the data in Group 1 and also to the mercury values in Group 2. Analyses were conducted without these mercury values for each tissue response. When the mercury concentration in liver on day 49 was removed, mercury uptake was significantly different for the two mallard groups ($F_{2,30} = 3.5$, $p < 0.05$). The lack-of-fit test was not significant when applied to each group separately (Group 1: $F_{4,5} = 1.18$, $p > 0.05$; Group 2: $F_{6,15} = 2.5$, $p > 0.05$). When the value for day 77 was removed for the mercury concentrations in kidney, the linear model was adequate for the combined data ($F_{9,23} = 1.93$, $p > 0.05$). Figures 26 and 27 show the increasing uptake of mercury by liver and kidney, respectively, in the domestic ducks with the designated values removed. However, the results indicate that these conclusions for mercury accumulation in liver and kidney should be regarded with caution.

3.3.3. Waterfowl Food Sources

The gizzard contents of several ducks were examined to identify foods consumed by the birds. Duckweed was a common food item for several duck

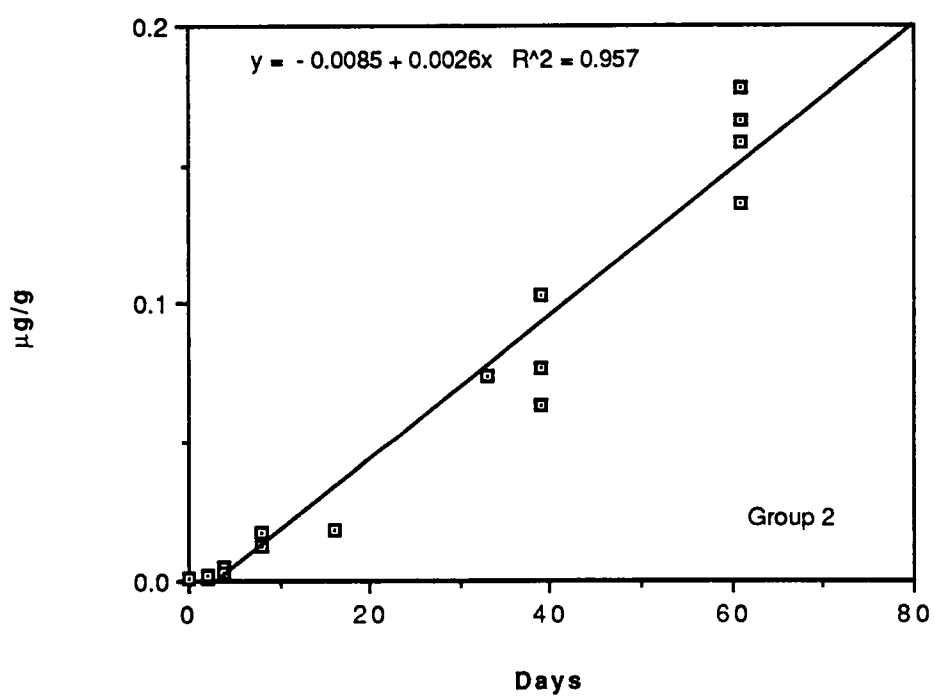
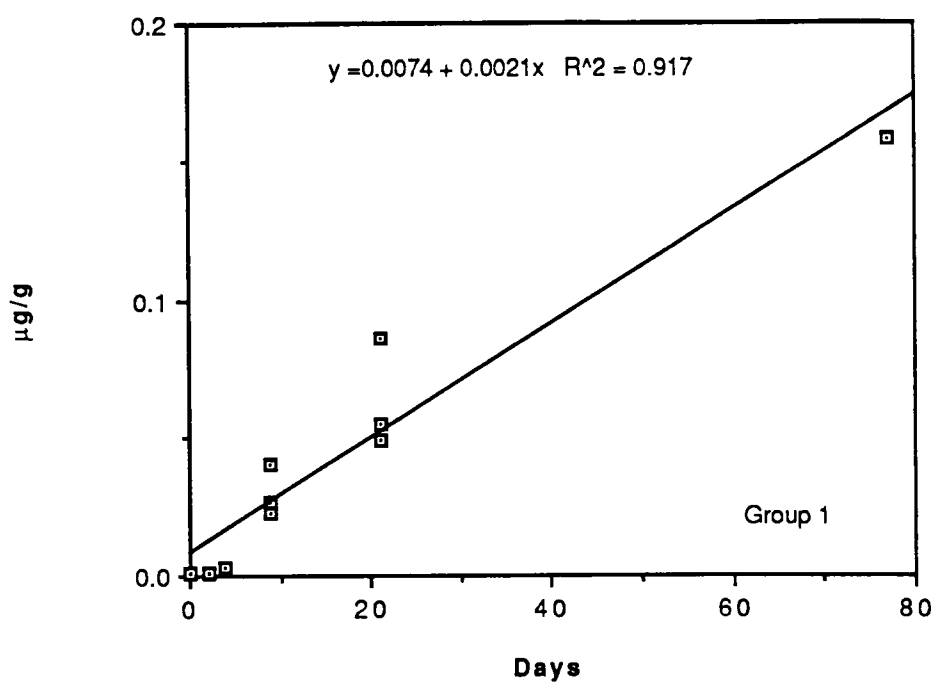


Figure 26. Mercury uptake by liver in each group of WOL domestic mallards.

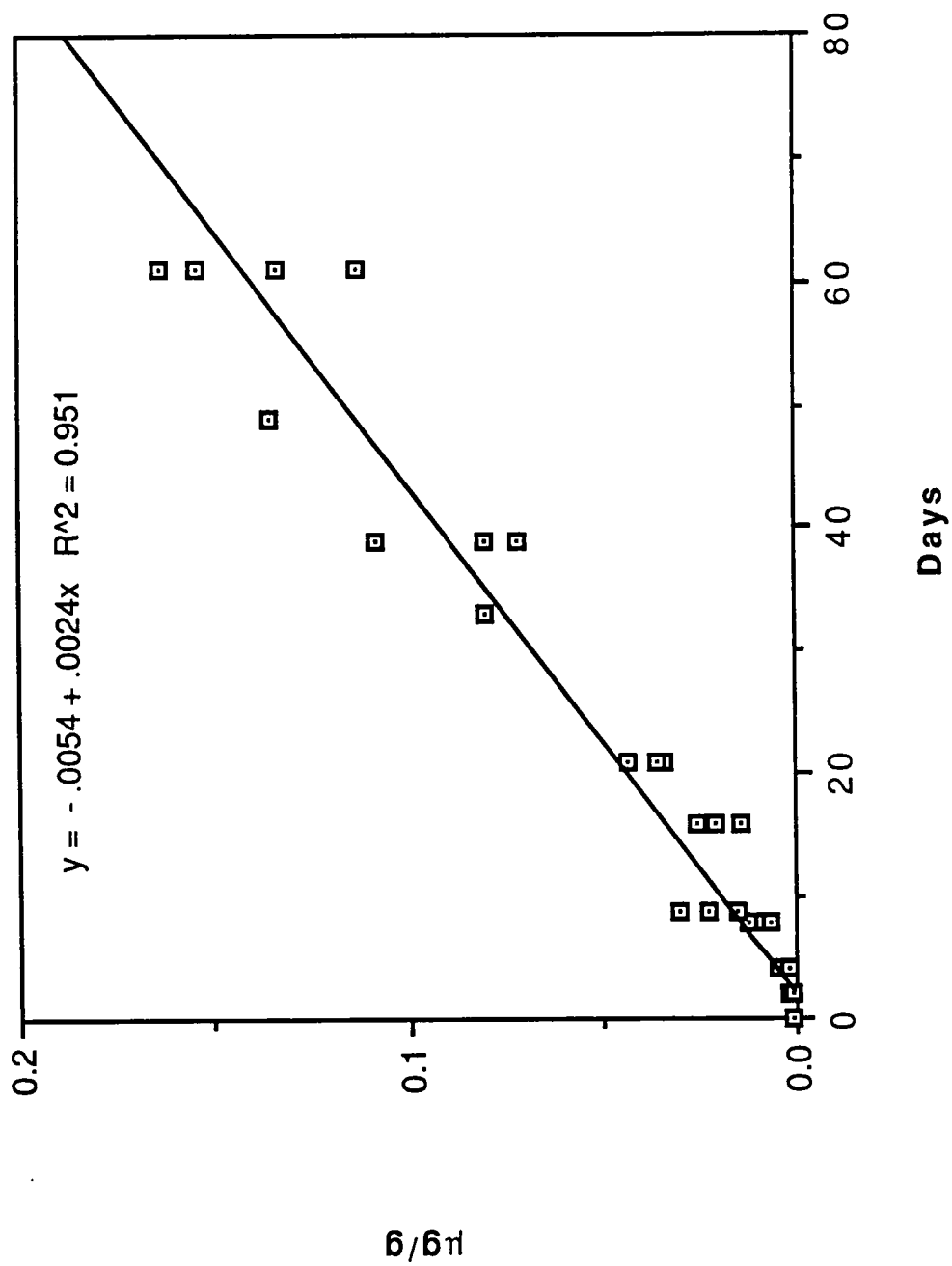


Figure 27. Mercury uptake by kidney for combined data from WOL domestic mallards.

species. Wood ducks consumed a variety of foods ranging from duckweed to frogs (Table 10). However, food sources could not be identified for several birds because their gizzards were essentially empty when analyzed except for a small amount of gravel.

Table 10. Foods found in gizzards of waterfowl collected from WOLA^a.

Waterfowl Species	Food Sources	Contents Found in Gizzards
Wood Duck	vegetation animal matter	duckweed, acorns tadpoles, frogs, dragonfly nymphs
Black Duck	vegetation animal matter	duckweed, algae dragonfly nymphs, snails, tadpoles
Gadwall	vegetation animal matter	N.D. ^b
Mallards (domestic)	vegetation animal matter	duckweed, algae None

^aSediment and gravel present in all waterfowl gizzards analyzed.

^bN.D. = Not able to determine contents in gizzard.

CHAPTER 4

DISCUSSION

4.1. WATERFOWL CENSUS

The attractiveness of waste ponds and streams to waterfowl and other animals should be considered in waste management practices. Many of the settling basins, waste ponds and streams on the ORR are attractive to waterfowl species as indicated by the waterfowl census, especially during the fall and winter. Fitzner and Price (1973) also showed that the greatest use of waste ponds by waterfowl was during the fall/winter season. Lower numbers of birds observed in the spring and summer may be attributed to several factors. First, most of the waterfowl using the streams and ponds nest in spring and summer, which reduces visibility of the birds. Second, these months do not fall within a migration period. Third, most of the waterfowl have migrated north by the spring and summer.

Dabbling duck species prefer to inhabit shallow areas which are characteristic of most of the waste disposal ponds on the ORR. Small, shallow ponds are generally less attractive to diving birds; thus, fewer numbers of diving ducks were observed on the ORR aquatic areas. Although many waterfowl species observed at ORR are migratory and only use ORR ponds for a limited period, resident and seasonal populations of species such as Canada geese, wood duck, mallard, and ring-necked duck may occupy these areas for extended periods.

4.2 CANADA GEESE BANDING STUDY

The available data indicated that the collared Canada geese are probably resident birds, especially those banded at ORGDP. The trends indicated by Figures 15-17 show that the number of collared geese observed is decreasing over time as the total number of geese observed is relatively constant. The decrease in the number of collared geese at ORGDP (week 31) correlates with the initiation of the nesting season for resident Canada geese in east Tennessee. Because geese are more territorial and remain close to the nest site during this season, the geese would be less visible in comparison to other periods of the year. Other factors contributing to the decline of collared geese would include mortality, but this would not be responsible for such a decrease in the number of geese observed. A more significant factor responsible for this decline is probably the dispersal of geese off the ORR to areas not currently censused. The total goose population remains fairly constant due to immigration and emigration. Furthermore, the small number of collared geese in comparison to the total number of local geese may bias the data analyses.

Because the ORR provides excellent habitat for Canada geese, the birds remain in the general area year round. The geese may disperse to public parks or private lands to feed, but return to their roosting areas. The increase in total geese observed during the winter months indicates that the ORR and other census sites are used by migratory geese. This Canada geese banding study indicates that a potential for transport of contamination off the ORR exists through both resident and migratory geese. Populations of

geese intermingle and use the ORR and surrounding public areas extensively. Canada geese may transport radioactive and nonradioactive contamination off the ORR externally, internally and via their feces.

The Canada goose census indicated that the geese collared at ORGDP did not travel far from their initial banding site. The lack of movement indicated by the data may be biased by the methods of the study. The census sites were visited at approximately the same time each week; thus, the geese were only observed during a short period of their daily cycle. If this banding study continues, geese may be censused throughout the day and censused more frequently. Melton Hill Reservoir and the Clinch River could be censused two to four times a month. Possibly the ORR census could be conducted two or three times a week. Increasing the number of times the geese are censused may increase the number of observations of a particular neck-collared goose; thus, more accurate conclusions could be drawn from the data regarding the movements of a particular bird. Furthermore, this study requires continued observations for at least three to five years and more detailed analyses conducted on the data so specific characteristics of the population may be identified.

4.3. CONTAMINANTS IN WATERFOWL AND COOTS

Although waterfowl and other waterbirds utilizing waste disposal areas on the ORR readily accumulate ^{137}Cs , ^{90}Sr , ^{60}Co , mercury, selenium, and cadmium in their tissues, the levels generally do not exceed standard limits. However, food chain studies have shown that the concentrations of some pollutants, especially mercury, selenium, and ^{137}Cs , can be magnified in

consumer organisms such as waterfowl (Fitzner and Price 1973, Hutchinson and Meema 1987, DuBowy 1989). Canada geese collected from Basin 3524 retained higher concentrations of ^{137}Cs in muscle than geese collected from the same area in 1986. The breast tissue from the Basin 3524 Canada geese contained higher ^{137}Cs levels than gizzard contents. This may indicate that these birds had not been feeding exclusively from Basin 3524 in the period before the geese were collected, or that ^{137}Cs may be biomagnified through the food chain. A person consuming a dabbling duck (gadwall) from WOL contaminated with the maximum concentrations of ^{137}Cs in breast tissue (340 Bq/kg), would have to eat 217 kg of tissue to exceed the 1 mSv (100 mrem) recommended annual dose limit (Gilbert et al. 1985). However, only 520 g of breast tissue from the Basin 3524 Canada goose with the maximum ^{137}Cs concentrations need be consumed to exceed the recommended dose. In comparison, if breast tissue from the Canada goose with the maximum ^{137}Cs concentrations (1750 Bq/kg) collected during the 1988 banding operation was consumed, a person would have to eat 42 kg to exceed 1 mSv/yr. Because several of the waste ponds and streams on the ORR border public waterways, there is potential for a hunter to harvest a contaminated waterfowl.

Levels of mercury and cadmium in all ORR waterfowl analyzed did not exceed recommended levels for consumption by humans (Hutchinson and Meema 1987, Lappenbusch 1988). Silver was accumulated by some of the WOL domestic mallards and one WOL wood duck. However, Lappenbusch (1988) suggested that the acceptable daily intake for humans is none. If so, no tissue from waterfowl contaminated with silver should be consumed. The maximum acceptable daily intake for selenium is 200 $\mu\text{g/day}$ (Ohlendorf et al. 1986, Lappenbusch 1988, Dubowy 1989). The California State Department

of Health Services recommended that the maximum allowable selenium concentration in duck tissue is 1 to 2 $\mu\text{g/g}$ wet weight (Dubowy 1989). Waterfowl from the ORR accumulated selenium residues in breast tissue approximating but not exceeding the 1 to 2 ppm (except for two domestic mallards), but some liver and kidney samples contained up to 6 $\mu\text{g/g}$.

The highest concentrations of cadmium, mercury, and selenium were found in the liver or kidney as was previously determined by Ford et al. (1975), Mayack et al. (1981), Frank et al. (1983), and Heinz et al. (1987). Mercury concentrations detected in ORR waterfowl were generally lower than levels reported for waterfowl collected in Canada and South Dakota (Vermeer et al. 1973, Hesse et al. 1975, Pearce et al. 1976, Driver and Derksen 1980). These concentrations were also lower than mercury levels demonstrated to be adverse for reproduction in waterfowl (Hesse et al. 1975, Finley and Stendell 1978). The WOL wood ducks retained mercury residues comparable to concentrations determined in wood ducks collected from the mercury-contaminated Holston River, Tennessee (Lindsay and Dimmick 1983). Mean levels of cadmium and lead reported in freshwater herbivores (dabbling duck species) obtained from the Chesapeake Bay were higher than those concentrations detected in migratory dabblers collected from WOL (DiGiulio and Scanlon 1984b). The 33 $\mu\text{g/g}$ of lead determined in tissues from one WOL transient mallard and the 3.2 to 240 $\mu\text{g/g}$ of lead in kidneys from five WOL domestic mallards may be influenced by the lead shot used to collect the ducks. Lead concentrations were relatively low in other waterfowl tissues sampled. Liver and kidney cadmium concentrations in several WOL domestic mallards approached the values of 0.64 to 1.2 $\mu\text{g/g}$ in liver and 5.7 to 17 $\mu\text{g/g}$ in kidney of cadmium in freshwater herbivores reported by DiGiulio and

Scanlon (1984b). Selenium concentrations in several ORR waterfowl including the domestic mallards approximated the lower spectrum of 1.0 to 9.5 $\mu\text{g/g}$ selenium levels detected in Kesterson Reservoir waterfowl (Ohlendorf et al. 1986)

Concentrations of metals detected in adult wood ducks were statistically higher than in immatures for only cadmium in kidney and selenium in breast tissue. Although the statistical results were biased by the unequal/small sampling size, cadmium and selenium concentrations were probably higher in adults because they may have fed in areas other than WOL that contained higher metal concentrations. Furthermore, the adults may have retained metals in their tissues from previous exposures. Cadmium concentrations in exposed organisms tends to increase with age (Eisler 1985a). The mean ^{90}Sr concentrations in bone were also higher in immatures than in the adults although this difference was not statistically significant. Strontium-90 is an antilog of calcium, and therefore will accumulate in the bone. Because the immature birds are still building bone mass, they may accumulate higher concentrations of ^{90}Sr . However, ^{90}Sr has a relatively long biological half-life in bone because of the slow exchange of materials in bone. Thus, ^{90}Sr can be detected in an organism after a longer period than ^{137}Cs and may build up in bone over time (Reichle et al. 1970, Whicker and Schultz 1982).

The wood ducks were expected to accumulate higher concentrations of ^{137}Cs in tissues than the WOL migratory waterfowl because they are more characteristic of a resident population on WOL and utilize the ^{137}Cs -contaminated WOL extensively during the summer. However, the average ^{137}Cs concentration in the transient waterfowl was higher than in the wood

ducks. These results may be due to differences (1) in food preferences, (2) of radionuclide concentrations in food sources, possibly seasonal, or (3) differences among species and between ages. Adult wood ducks prefer acorns when they are available (Bellrose 1976). Acorns would be less contaminated than foods such as invertebrates and aquatic plants taken directly from the sediments of WOL. Thus, adult wood ducks may retain lower radionuclide concentrations in tissues in comparison to other waterfowl species and especially to young juvenile wood ducks who consume a higher proportion of animal foods. Cesium-137 can bioaccumulate in a food chain because it has a high transfer coefficient in organic matter. For example, ^{137}Cs increases in concentration in each level of the lichen-caribou-man food chain (NCRP 1977).

Wood ducks accumulated slightly higher mercury and selenium concentrations in tissues, especially in liver and kidney, than in the migratory birds. This difference is probably due to the higher proportion of animal foods in the diet of these wood ducks as indicated by examination of their gizzard contents. Both mercury and selenium can be biomagnified in the food chain (Hutchinson and Meema 1987, Saiki and Lowe 1987, DuBow 1989). However, differences in species, age, and other biological and physical parameters may affect the uptake of contaminants.

To compare contaminant residues among the species and individuals of migratory waterfowl collected from WOL would be difficult because their residence time on the lake could not be determined. Differences in concentrations among species and seasons did not prove to be significant for ^{137}Cs concentrations in breast tissue. Mercury concentrations in breast tissue for species collected in 1988-89 may be significantly different due to

variations in food sources. Black ducks include a larger proportion of animal matter in their diet in comparison to gadwalls and mallards (Bellrose 1976). Because mercury is biomagnified in the food chain, organisms that feed on several trophic levels may accumulate higher concentrations of contaminants in their tissues than those organisms that feed mostly on vegetation (Finley and Stendell 1978). Furthermore, the unequal sampling size probably biased the statistical results, especially for ^{90}Sr in bone, so the conclusions regarding the statistical differences in these ducks should be regarded with caution.

In comparison to the migratory ducks collected from WOL, ORNL Canada geese retained higher concentrations of ^{137}Cs in their tissues. However, higher levels of contaminants are available in the process waste basins (Basins 3524, 3513) at ORNL than in WOL. Concentrations of ^{137}Cs and ^{60}Co varied considerably among the Canada geese sampled from ORNL. This wide range in contaminant levels is a result of the residence time at a waste pond and the radionuclide levels in pond sediments and other biota. The concentrations of metals in tissues did not differ greatly among the Canada geese nor between the geese and migratory waterfowl.

The domestic mallard experiment on WOL indicated that waterfowl increase their tissue concentrations of ^{137}Cs , ^{90}Sr , and mercury over time. Although Group 1 and Group 2 mallards showed similar trends in contaminant accumulation in their tissues, statistical differences between the two groups for concentrations of mercury in breast tissue, mercury by liver, and ^{137}Cs by kidney may be a result of seasonal differences in uptake. Seasonal fluctuations in the accumulation of radioactive materials in organisms result from variations in metabolic rates, temperature, and feeding rates (Davis and

Foster 1958). Furthermore, the insufficient data collected for Group 1 may have biased the comparison of the accumulation of contaminants in mallard tissues. Cesium-137 uptake by whole body, breast tissue, and liver, ^{90}Sr by bone, and mercury by kidneys do not appear to be influenced by seasonal differences in food sources because a significant difference in contaminant uptake was not determined between the two groups. Possibly a sigmoidal model as described in Brisbin et al. (1990) is needed to determine the uptake for ^{137}Cs by whole body and liver because a linear model was not adequate. Whole body ^{137}Cs concentrations were greater than in liver and this was probably due to external contamination.

The contaminant concentrations in mallards sampled on the same day are relatively similar, especially those birds collected before Day 20. The domestic mallards tended to remain in tight groups during the first few weeks after release on WOL and foraged in the same areas of the lake. As the ducks became more accustomed to the WOL environment, they used more of the lake area and divided into smaller groups to feed. Thus, the variation in contaminant concentrations among ducks collected on the same day increased over time because they were exposed to different levels of contamination in foods and sediment. Because certain areas of WOL are known to contain higher levels of contamination than others (Loar 1988b), the levels of radioactive and nonradioactive contaminants in duck tissues may reflect the WOL areas frequented.

Variability in radionuclide concentrations in whole body for mallards collected on the same day is expected because whole body residues are influenced by both external and internal concentrations. Surface contamination could vary considerably from one duck to another. Similarity of

contaminant levels in tissues/organs would be influenced more by specific duck behaviors. Furthermore, pollutant concentrations in filtering organs such as liver and kidney would also fluctuate because they are more affected by contaminant levels in foods recently consumed by ducks.

Higher concentrations of ^{90}Sr were observed in the immature mallards in Group 2 than in the adults. Since ^{90}Sr accumulates in bone and the immature birds are still building bone mass, the immature birds may accumulate higher concentrations of ^{90}Sr .

Cesium-137 and mercury concentrations in transient or migratory ducks that use WOL were in the same range as concentrations in the domestic mallard tissues. Therefore, these migratory dabbling ducks probably spent less than two to three months on WOL before they were sampled. The length of time a migratory dabbling duck may reside on WOL may be estimated by comparing the contaminant concentration in their tissues with the domestic mallard uptake curve.

Although the coots spent approximately the same amount of time on WOL, their tissue radionuclide concentrations were higher than the highest levels in the domestic mallard tissues. Coots forage primarily on submerged vegetation obtained by diving but also feed on vegetation, insects, and aquatic animal life along the shoreline (Johnsgard 1975). Therefore, coots may retain higher radionuclide concentrations because of different levels of radionuclides in their food sources. In addition, coots may ingest more sediment when feeding on aquatic life or along the shoreline. The sediment in aquatic ecosystems generally accumulate the highest concentrations of radionuclides (Whicker and Schultz 1982, Loar 1989).

Ducks and geese are both migratory and locally mobile and many are important game species; thus, these birds may serve as vectors in transporting radionuclide and metal contamination into the human food chain.

Contamination may be accumulated both internally and externally by an organism inhabiting a waste disposal pond or stream. Internal contamination is a major concern to consumers of waterfowl and of consequence to the duck (Fitzner and Price 1973). Waterfowl are a means by which contaminants can be transported from waste ponds to an uncontaminated area.

Accumulation of radionuclides and metals by a bird and the tissues in which the contaminants concentrate are dependent on the biological half-life of the particular contaminants and the physical half-life of radionuclides, as well as many physical, chemical, and biological factors. Concentrations of pollutants will vary according to species, tissues, food habits, life cycles, and seasonal changes (Davis and Foster 1958). Therefore, how much contamination an individual bird accumulates from the ORR and the potential dose to humans from the consumption of a contaminated bird are dependent on (1) the levels of contamination available in the waste disposal areas, (2) the length of time a bird resides in a contaminated area, and (3) feeding habits and other biological characteristics of the individual bird. Basin 3524 at ORNL contributed a significant radionuclide body burden to Canada geese in a relatively short time period; waterfowl and coots using WOL do not accumulate high radionuclide or metal concentrations in a similar period.

CHAPTER 5

CONCLUSIONS

The waterfowl census showed that migratory and resident waterfowl as well as other waterbirds utilize both contaminated and uncontaminated areas on the ORR. A greater abundance of waterfowl was observed on White Oak Lake in comparison to other contaminated areas censused at ORNL. White Oak Lake, the largest contaminated basin censused at ORNL, provides a resting and wintering area for migratory waterfowl as well as excellent nesting habitat for wood ducks. Areas at the Y-12 Plant, ORGDP, and ORNL were used extensively by Canada geese.

Neck-collared Canada geese were observed at the ORR, the Clinch River, and Melton Hill Reservoir, but generally did not travel far from the site at which they were banded. Most of the observations for the geese collared at ORGDP occurred at sites less than 1 km from the initial banding area.

Waterfowl obtain ^{137}Cs , ^{60}Co , ^{90}Sr , mercury, selenium, cadmium, silver, and lead from inhabiting ORR contaminated sites. Metal residues in ORR waterfowl did not exceed or were comparable to concentrations in ducks from other potentially contaminated regions of the United States and Canada. Cesium-137, ^{90}Sr , and mercury concentrations in waterfowl increase with time up to 95 days when birds occupy contaminated sites as indicated by the domestic mallard experiment on WOL.

Levels of contaminants in the tissues of waterfowl collected from the ORR waste disposal areas depend on (1) the levels of contamination present in the sediment, water, and biota of the waste area, (2) the length of time the

bird resides in the contaminated area, and (3) the feeding habits and other biological characteristics of the bird.

Judged by the data from the domestic mallard experiment, migratory dabbling ducks generally do not inhabit WOL for more than 60 to 95 days. Therefore, migratory waterfowl using WOL would not accumulate significant levels of contaminants in their tissues. However, there is potential for waterfowl to utilize WOL for much longer periods. If a person were to consume tissue from a migratory waterfowl contaminated with the maximum levels determined in transient ducks (gadwall) from WOL, the potential dose commitment would only be 1.4 $\mu\text{Sv/yr}$. However, Canada geese do use some of the more highly contaminated waste ponds at ORNL. Consumption of 1600 grams of breast tissue from a goose that had used Basin 3524 for approximately one month would more than triple the recommended dose limit of 1 mSv/yr (100 mrem/yr) for a human. Thus, Canada geese and other waterfowl may serve as a vector in transporting radionuclides and metals off the ORR and into the human food chain.

LITERATURE CITED

LITERATURE CITED

- Abraham, R. L. 1972. Mortality of mallards exposed to gamma radiation. *Radiation Research* 49:322-327.
- Annett, C.S., F.M. D'Itri, J.R. Ford, and H.H. Prince. 1975. Mercury in fish and waterfowl from Ball Lake, Ontario. *J. Environ. Qual.* 4:219-222.
- Ashwood T.L., C.R. Olsen, L.L. Larsen, and P.D. Lowry. 1986. Sediment contamination in streams surrounding the Oak Ridge Gaseous Diffusion Plant. ORNL/TM-9791, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 32 pp. and appendices.
- Barton, K. 1987. Federal wetlands protection programs. pp. 179-198. IN: Roger L. Silvestro (ed.), *Audubon Wildlife Report 1987*. Academic Press, New York. 697 pp.
- Bellrose, F.C. 1959. Lead poisoning as a mortality factor in waterfowl populations. *Illinois Nat. Hist. Surv. Bull.* 27:235-288.
- Bellrose, F.C. 1976. *Ducks, geese, and swans of North America*. Harrisburg, PA: Stackpole Books. 540 pp.
- Blus, L.J., R.K. Stroud, B. Reiselig, and T. McEneaney. 1989. Lead poisoning and other mortality factors in trumpeter swans. *Environ. Toxicol. and Chem.* 8:263-271.
- Bogle, M.A., and R.R. Turner. 1989. Rogers Quarry water balance January 1, 1987 through June 30, 1988. Y/TS-506. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 92 pp.
- Boyle J.W., R. Blumberg, S.J. Cotter, G.S. Hill, C.R. Kerley, R.H. Ketelle, R.L. Kroodsmas, D.W. Lee, R.C. Martin, R.D. Roop, D.N. Secora, W.P. Staub, and R.E. Thoma. 1982. Environmental analysis of the operation of the Oak Ridge National Laboratory (X-10 Site). ORNL-5870, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 185 pp. plus appendices.
- Braunstein, H.M., W.A. Alexander, H.M. Hubbard, T.W. Oakes, and W.F. Ohnesorge. 1984. An investigation of the concentration, distribution, and inventory of radionuclides in the sediment of Process Waste System Basin 3524. ORNL/TM-8682. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 43 pp.
- Brisbin, Jr. I.L., and J. Swinebroad. 1975. The role of banding studies in evaluating the accumulation and cycling of radionuclides and other environmental contaminants in free-living birds. *EBBA News* 38:186-192.

Brisbin, Jr. I.L., R.A. Griger, and M.H. Smith. 1973. Accumulation and redistribution of radiocesium by migratory waterfowl inhabiting a reactor cooling reservoir. pp. 373-383. IN: Environmental Behavior of Radionuclides Released in the Nuclear Industry. International Atomic Energy Agency, Vienna.

Brisbin, I.L., Jr., M.C. Newman, S.G. McDowell, and E.R. Peters. 1990. The prediction of contaminant accumulation by free-living organisms: applications of a sigmoidal model. Bull. Environ. Chem. and Toxicol. 9:141-149.

Chandler, W. J. 1987. Migratory bird protection and management. pp. 83-105. IN: Roger Silvestro (ed.), Audubon Wildlife Report 1987. Academic Press, New York. 697 pp.

Chupp N.R., and P.D. Dalke. 1964. Waterfowl mortality in Coeur d'Alene River Valley, Idaho. J. Wildl. Manage. 28:692-702.

Cox, D.K., N. Farrow, W.C. Kyker, and L.M. Stubbs. 1988. White survey-- the new definitive map of White Oak Lake. ORNL/TM (In review).

Curnow, R.D., F.A. Glover, and F.W. Whicker. 1970. Radiosensitivity of the mallard duck (*Anas platyrhynchos*). Colorado Cooperative Wildlife Research Unit. U.S. Atomic Energy Commission.

Cushing, C.E., and D.G. Watson. 1974. Aquatic studies of Gable Mountain Pond. BNWL-1884. Battelle Pacific Northwest Laboratories, Richland, Washington. 24 pp.

Custer T.W., and B.L. Malhern. 1983. Heavy metal residues in prefledgling black-crowned night-herons from three atlantic coast colonies. Bull. Environ. Contam. Toxicol. 30:178-185.

Davis, J.J., and R.F. Foster. 1958. Bioaccumulation of radioisotopes through aquatic food chains. Ecology 39:530-535.

Di Giulio, R.T. 1982. The occurrence and toxicology of heavy metals in Chesapeake Bay waterfowl. Dissertation Abstracts International Pt. B - Sci. and Engin. 44 (1) July 1983.

Di Giulio, R.T., and P.F. Scanlon. 1984a. Effects of cadmium and lead ingestion on tissue concentrations of cadmium, lead, copper, and zinc in mallard ducks. Sci. Total Environ. 39:103-110.

Di Giulio, R.T., and P.F. Scanlon. 1984b. Heavy metals in tissues of waterfowl from the Chesapeake Bay, USA. Environ. Poll. (Series A) 35:29-48.

Domby, A.H., D. Paine, and R.W. McFarlane. 1977. Radiocesium dynamics in herons inhabiting a contaminated reservoir system. Health Physics 33:523-532.

- Driver, E.A., and A.J. Derksen. 1980. Mercury levels in waterfowl from Manitoba, Canada, 1971-72. *Pestic. Monit. J.* 14:95-101.
- DuBowy R.J. 1989. Effects of diet on selenium bioaccumulation in marsh birds. *J. Wildl. Manage.* 53:776-781.
- Eisler, R. 1985a. Cadmium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish. Wildl. Serv. Biol. Rep. 85 (1.2). 46 pp.
- Eisler, R. 1985b. Selenium hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish. Wildl. Serv. Biol. Rep. 85 (1.5). 57 pp.
- Eisler, R. 1987. Mercury hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish. Wildl. Serv. Biol. Rep. 85 (1.10). 90 pp.
- Eisler, R. 1988. Lead hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish. Wildl. Serv. Biol. Rep. 85 (1.14). 134 pp.
- Fendley, T.T., M.N. Manlove, and I.L. Brisbin, Jr. 1977. Accumulation and elimination of ^{137}Cs by naturally contaminated wood ducks. *Health Physics* 32:415-422.
- Fimreite N. 1970. Mercury uses in Canada and their possible hazards as sources of mercury contamination. *Environ. Pollut.* 1: 119-131.
- Fimreite, N. 1974. Mercury contamination of aquatic birds in Northwestern Ontario. *J. Wildl. Manage.* 38:120-131.
- Finley M.T., and R.C. Stendell. 1978. Survival and reproductive success of black ducks fed methylmercury. *J. Wildl. Manage.* 16:51-64.
- Fitzner, R.E., and K.R. Price. 1973. Use of Hanford waste ponds by waterfowl and other birds. BNWL-1738. Battelle Pacific Northwest Laboratory, Richland, Washington. 24 pp.
- Ford J.F. and H.H. Prince. 1975. Biological effects of methylmercury in aquatic systems on mallards and scaup. OWRR Project No. A-052-Mich, prepared for Office of Water Research and Technology National Science Foundation, March 1975. 75 pp.
- Francis C.W., and R.G. Stansfield. 1986. Groundwater monitoring at three Oak Ridge National Laboratory inactive waste impoundments: results after one year. ORNL/TM-10193, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 121 pp.
- Francis C.W., R.G. Stansfield, and D.R. Simpson. 1986. Characterization plan for the Old Hydrofracture Facility (OHF): CERCLA IIA. ORNL/TM-9991, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 75 pp.

Frank R., H. Lumsden, J.F. Barr, and H.E. Braun. 1983. Residues of organochlorines, insecticides, industrial chemicals, and mercury in eggs and in tissues taken from healthy and emaciated common loons, Ontario, Canada, 1968-1980. *Arch. Environ. Contam. Toxicol.* 12:641-654.

Gasaway, W.C., and I.O. Buss. 1972. Zinc toxicity in the mallard duck. *J. Wildl. Manage.* 36:1107-1117.

Gilbert, T.L., K.F. Eckerman, W.R. Hansen, J.W. Healey, W.E. Kennedy, Jr., B.A. Napier, and J.K. Soldat. 1985. A manual for implementing residual radioactivity guidelines. Review Draft.

Greichus Y.A., A. Greichus, and R.J. Emerick. 1973. Insecticides, polychlorinated biphenyls, and mercury in wild cormorants, pelicans, their eggs, food and environment. *Bull. Environ. Contam. and Toxic.* 9:321-328.

Haase, C.S., H.L. King, G.A. Gillis, and C.W. Kimbrough. 1987. Preliminary hydrological and hydrochemical assessment of the Beta-4 Security Pit, the Kerr Hollow Quarry, the Ravine Disposal, the Rogers Quarry, and the United Nuclear Sites at the Oak Ridge Y-12 Plant. Y/TS-271. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Haegle M.A., R.K. Tucker, and R.H. Hudson. 1974. Effects of dietary mercury and lead on eggshell thickness in mallards. *Bull. Environ. Contam. and Toxic.* 11:5-11.

Halford D.K. 1983. Effects of cooking on radionuclide concentrations in waterfowl tissues. pp. 399 - 402. IN O.D. Markham (ed.) Idaho National Engineering Laboratory Radioecology and Ecology programs 1983 Progress Report. DOE/ID-12098, Idaho National Engineering Laboratory, Idaho Falls, Idaho.

Halford D.K., and O.D. Markham. 1984. Iodine-129 in waterfowl muscle from a radioactive leaching pond complex in southeastern Idaho. *Health Physics* 46:1259-1263.

Halford, D.K., O.D. Markham, and R.L. Dickson. 1982. Radiation doses to waterfowl using a liquid radioactive waste disposal area. *J. Wildl. Manage.* 46:905-914.

Halford, D.K., O.D. Markham, and G.C. White. 1983. Biological elimination rates of radioisotopes by mallards contaminated at a liquid radioactive waste disposal area. *Health Physics* 45:745-756.

Halford, D.K., J.B. Millard, and O.D. Markham. 1978a. Radionuclide concentrations in wild waterfowl using the test reactor area radioactive leaching pond. pp. 47-55. IN: O.D. Markham (ed.) Ecological Studies on the Idaho National Engineering Laboratory Site 1978 Progress Report. IDO-12087. U.S. Department of Energy.

Halford, D.K., J.B. Millard, and O.D. Markham. 1981. Radionuclide concentrations in waterfowl using a liquid radioactive waste disposal area and the potential radiation dose to man. *Health Physics* 40:173-181.

Halford, D.K., J.B. Millard, and R.G. Schreckhise. 1978b. Retention of activation and fission radionuclides by mallards from the test reactor area radioactive leaching ponds. pp. 56-63. IN: O.D. Markham (ed.), Ecological Studies on the Idaho National Engineering Laboratory Site 1978 Progress Report. IDO-12087. U.S. Department of Energy.

Heinz G.H. 1974. Effects of low dietary levels of methylmercury on mallard reproduction. *Bull. Environ. Contam. and Toxicol.* 11:386-392.

Heinz, G.H. 1979. Methylmercury: reproductive and behavioral effects on three generation of mallard ducks. *J. Wildl. Manage.* 43:394-401.

Heinz, G.H., and L.G. Gold. 1987. Behavior of mallard ducklings from adults exposed to selenium. *Environ. Toxicol. and Chem.* 6:863-865.

Heinz, G.H., D.J. Hoffman, and L.G. Gold. 1989. Impaired reproduction of mallards fed an organic form of selenium. *J. Wildl. Manage.* 53:418-428.

Heinz, G.H., D.J. Hoffman, A.J. Krynsky, and D.M.G. Weller. 1987. Reproduction in mallards fed selenium. *Environ. Toxicol. and Chem.* 6:423-433.

Herde, K.E., and J.F. Cline. 1949. Radioactivity in pekin ducks on the Columbia River. HW-12079. Hanford Works. U.S. Atomic Energy Commission. 11 pp.

Herde, K.E., R.L. Browning, and W.C. Hanson. 1951. Activity densities in waterfowl of Hanford Reservation and environs. HW-18645. U.S. Atomic Energy Commission. 14 pp.

Hesse, G.W., R.L. Brown, and J.F. Heisinger. 1975. Mercury contamination of birds from a polluted watershed. *J. Wildl. Manage.* 39:299-304.

Hoffman F.O., B.G. Blaylock, C.C. Travis, K.L. Daniels, E.L. Etnier, K.E. Cowser, and C.W. Weber. 1984. Preliminary screening of contaminants in sediments. ORNL/TM-9370, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 198 pp.

Hutchinson R.C., and K.M. Meema, eds. 1987. Lead, mercury, cadmium, and arsenic in the environment. Great Britain: John Wiley and Sons. pp. 360.

Johnsgard, P.A. 1975. North American Game Birds of Upland and Shoreline. Lincoln, Ne: University of Nebraska Press. 183 pp.

Kleinbaum, D.G., L.L. Kupper, and K.E. Muller. 1988. Applied regression analysis and other multivariable methods. Boston: PWS-Kent Publishing Company. 718 pp.

Konings, J., R. Kirchmann, G.B. Gerber, R. Van Bruwaene, and J. Colard. 1984. Distribution of ^{60}Co and ^{137}Cs in mallard ducks (*Anas platyrhynchos*). Health Physics 46:681-684.

Krapu, G.L., G.A. Swanson, and H.K. Nelson. 1973. Mercury residues in pintails breeding in North Dakota. J. Wildl. Manag. 37:395-399.

Krumholtz L.A. 1954. An ecological survey of the vertebrate fauna of White Oak Lake and environs. ORO-587 (Vol. III), U.S. Atomic Energy Commission, Oak Ridge, Tennessee. 208 pp.

Lappenbusch, W.L. 1988. Contaminated waste sites, property and your health. Virginia: Lappenbusch Environmental Health, Inc. 360 pp.

Lindsay R.C., and R.W. Dimmick. 1983. Mercury residues in wood ducks and wood duck foods in eastern Tennessee. Wildl. Diseases 19:114-117.

Loar J.M., ed. 1987. First annual report on the Oak Ridge National Laboratory biological monitoring and abatement program. ORNL/TM-10399. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 354 pp.

Loar J.M., ed. 1988a. Second annual report on the Oak Ridge National Laboratory biological monitoring and abatement program. Draft ORNL/TM Report, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 475 pp.

Loar J.M., ed. 1988b. First annual report on the Y-12 Plant biological monitoring and abatement program. Draft ORNL/TM Report, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 311 pp.

Loar J.M., ed. 1989. Third annual report on the Oak Ridge National Laboratory biological monitoring and abatement program. Draft ORNL/TM Report, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Loar, J.M., J.A. Solomon, and G.F. Cada. 1981a. Technical background information for the ORNL environmental and safety report, vol. 2: a description of the aquatic ecology of White Oak Creek Watershed and the Clinch River below Melton Hill Dam. ORNL/TM-7509/V2. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 198 pp.

Loar J.M., F.A. Burkhart, G.F. Cada, J.W. Huckabee, J.T. Kitchings, K.D. Kumar, A.M. Sasson, J.A. Solomon, and J.D. Story. 1981b. Ecological studies of the biotic communities in the vicinity of the Oak Ridge Gaseous Diffusion Plant. ORNL/TM-6714, Oak Ridge National Laboratory, Oak Ridge, Tennessee. 321 pp.

Lomenick, T.F., and D.A. Gardiner. 1965. The occurrence and retention of radionuclides in the sediments of White Oak Lake. *Health Physics* 11:567-577.

Lowe, V.P.W. and A.D. Horrill. 1986. Transfer of radionuclides to man from Greylag geese *Anser anser* and wigeon *Anas penelope* grazing the salt marshes at Ravensglass. *J. Environ. Radioactivity* 4:101-121.

Markham O.D., D.K. Halford, S.K. Rope, and G.B. Kuzo. 1988. Plutonium, Am, Cm, and Sr in ducks maintained on radioactive leaching ponds in southeastern Idaho. *Health Physics* 55:517-524.

Mautino M., and J.U. Bell. 1987. Hematological evaluation of lead intoxication in mallards. *Bull. Environ. Contam. Toxicol.* 38:78-85.

Mayack, L.A., P.B. Bush, O.J. Fletcher, R.K. Page, and T.T. Fendley. 1981. Tissue residues of dietary cadmium in wood ducks. *Arch. Environ. Contam. Toxicol.* 10:637-645.

Millard, J.B., F.W. Whicker, and O.D. Markham. 1978a. Barn swallows nesting near radioactive leaching ponds in southeastern Idaho pp. 1-14. IN: O.D. Markham (ed.), *Ecological Studies on the Idaho National Engineering Laboratory Site 1978 Progress Report*. U.S. Department of Energy.

Millard, J.B., F.W. Whicker, and O.D. Markham. 1978b. Gamma emitting radionuclides of the reactor area leaching ponds. pp. 28-46. IN: O.D. Markham (ed.), *Ecological Studies on the Idaho National Engineering Laboratory Site 1978 Progress Report*. IDO-12087. U.S. Department of Energy.

National Council on Radiation Protection and Measurements (NCRP). 1977. Cesium-137 from the environment to man: metabolism and dose. NCRP Report No. 52. Bethesda, MD. 48 pp.

National Council on Radiation Protection and Measurements (NCRP). 1985. SI units in radiation protection and measurement. NCRP Report No. 82. Bethesda, MD. 64 pp.

Oakes, T.M., B.A. Kelly, W. F. Ohnesorge, J.S. Eldridge, J.C. Bird, K.E. Shank, and F.S. Tsakeres. 1982. Technical background information for the environmental and safety report, vol. 4: White Oak Lake and Dam. ORNL-5681. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 233 pp.

Oakes, T.W., P.M. Pritz, S.T. Goodpasture, S.F. Huang, C.S. Gist, C.W. Weber, F.M. O'Hara, and C.W. Kimbrough. 1987. Environmental surveillance of the U.S. Department of Energy Oak Ridge Reservation and surrounding environs during 1986. Volume 2: data presentation. pp. 437-444. ES/ESH-1. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 522 pp.

Ohlendorf, H.M., D.J. Hoffman, M.K. Saiki, and T.W. Aldrich. 1986. Embryonic mortality and abnormalities of aquatic birds: apparent impacts of selenium from irrigation drainwater. *Sci. Total Environ.* 52:49-63.

Pearce, P.A., I.M. Price, and L.M. Reynolds. 1976. Mercury in waterfowl from Eastern Canada. *J. Wildl. Manage.* 40:694-703.

Peterson, M. 1990. Poster presentation at international conference on metals in soil, plants, and animals. Orlando, Florida. April 30 to May 4, 1990.

Reichle, D.E., P.B. Dunaway, and D.J. Nelson. 1970. Turnover and concentration of radionuclides in food chains. *Nuclear Safety* 11:43-55.

Rogers, R.G., K.L. Daniels, S.T. Goodpasture, C.W. Kimbrough, and E.W. Whitfield. 1988. Environmental surveillance of the U.S. Department of Energy Oak Ridge Reservation and surrounding environs during 1987. Volume 1: narrative, summary, and conclusions. ES/ESH-4/V1. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 492 pp.

Rusch, D.H., and G. Swenson. 1987. A manual for collection and interpretation of data on movements and survival of neckbanded Canada geese. Wisconsin Cooperative Wildlife Research Unit. 23 pp.

Saiki, M.K., and T.P. Lowe. 1987. Selenium in aquatic organisms from subsurface agricultural drainage water, San Joaquin Valley, California. *Arch. Environ. Contam. Toxicol.* 16: 657-670.

Sanderson, G.C., and F.C. Bellrose. 1986. A review of the problem of lead poisoning in waterfowl. *Ill. Nat. Hist. Surv. Spec. Publ.* 4. 34 pp.

SAS Institute. 1985a. Introductory Guide for Personal Computers Version 6 Edition. Cary, North Carolina. 111 pp.

SAS Institute. 1985b. SAS Users Guide: Basics. SAS Institute, Cary, NC. 1289 pp.

Satterthwaite, F.E. 1946. An approximation distribution of estimates of variance components. *Biometrics Bull.* 2:110-114.

Sharma, R.P., and J.L. Shupe. 1977. Lead, cadmium, and arsenic residues in animal tissues in relation to those in their surrounding habitat. *Sci. Total Environ.* 7:53-62.

Stansfield, R.G. and C.W. Francis. 1986. Characterization of the 3513 Impoundment. ORNL/TM-9936. Oak Ridge National Laboratory, Oak Ridge, Tennessee. 125 pp.

Straney, D.O., B. Beaman, I.L. Brisbin, Jr, and M.H. Smith. 1975. Radiocesium in birds of the Savannah River Plant. Health Physics 28:341-345.

Tester, J.R., F. McKinney, and D. Siniff. 1968. Mortality of three species of ducks - *Anas discors*, *A. crecca*, and *A. clypeata* - exposed to ionizing radiation. Radiation Research 33:364-370.

Tiner, Jr. R.W. 1984. Wetlands of the United States: Current Status and Recent Trends. U.S. Fish and Wildlife Service. National Wetlands Inventory.

Vermeer, K. and F.A.J. Armstrong. 1972. Correlation between mercury in wings and breast muscles in ducks, J.Wildl. Manage. 36:1270-1273.

Vermeer, K., F.A.J. Armstrong, and D.R.M. Hatch. 1973. Mercury in aquatic birds at Clay Lake, Western Ontario. J. Wildl. Manage. 37:58-61.

Whicker, F.W., and V. Schultz. 1982. Radioecology: Nuclear Energy and the Environment Volume I. Florida: CRC Press, Inc. 212 pp.

White, D., and E. Cromartie. 1985. Bird use and heavy metal accumulation in waterbirds at dredge disposal impoundments, Corpus Christi, Texas. Bull. Environ. Contam. Toxicol. 34:295-300.

White, D.H., and M.T. Finley. 1978. Uptake and retention of dietary cadmium in mallard ducks. Environ. Research 17:53-59.

Willard, W.K. 1960. Avian uptake of fission products from an area contaminated by low-level atomic wastes. Science 132:148-150.

Winger P.V., C. Sieckman, T.W. May, and W.W. Johnson. 1984. Residues of organochlorine insecticides, polychlorinated biphenyls, and heavy metals in biota from Apalachicola River, Florida, 1978. J. Assoc. Off. Anal. Chem. 67:325-333.

World Health Organization (WHO). 1976. Environmental Health Criteria I: Mercury. United Nations Environment Programme and the World Health Organization, Geneva.

Zar, J.H. 1984. Biostatistical Analysis. Englewood Cliffs, N.J. Prentice-Hall. 718 pp.

APPENDIX

Table A-1. Radionuclide and metal concentrations in Canada geese collected at ORNL.

Date Collected	Goose Number	Sample Description	¹³⁷ Cs Bq/kg	Ag µg/g	Cd µg/g	Hg µg/g	Pb µg/g	Se µg/g
7/88	8026	Breast Tissue	1340	<0.2	<0.05	0.004	<0.1	<0.3
		Liver	690	<0.2	0.064	0.017	<0.1	0.6
7/88	8028	Breast Tissue	1240	<0.2	<0.05	0.005	<0.1	<0.3
		Liver	730	<0.2	0.185	0.011	<0.1	0.9
7/88	8032	Breast Tissue	1750	<0.2	<0.05	0.003	<0.1	<0.3
		Liver	670	<0.2	<0.05	0.066	<0.1	0.6
7/88	8033	Breast Tissue	760	<0.2	<0.05	0.008	<0.1	<0.3
		Liver	710	<0.2	0.077	0.034	<0.1	0.8
7/88	8035	Breast Tissue	860	<0.2	<0.05	0.002	<0.1	<0.3
		Liver	330	<0.2	0.599	0.012	0.3	1.4
7/89	A31E ^a	Breast Tissue	40					
		Liver	15					
		Kidney	20					
7/89	A33E ^a	Breast Tissue	90					
		Liver	35					
		Kidney	40					
7/89	A37E	Breast Tissue	110	<0.2	<0.05	0.001	<0.1	0.3
		Liver	35	<0.2	0.61	0.020	0.1	0.8
		Kidney	41	<0.2	1.8	0.015	0.3	0.6
7/89	A38E ^a	Breast Tissue	104					
		Liver	41					
		Kidney	60					
7/89	A40E	Breast Tissue	163	<0.2	0.05	0.002	<0.1	<0.3
		Liver	63	<0.2	0.65	0.017	0.1	0.8
		Kidney	81	<0.2	1.4	0.013	0.2	0.7
7/89	A41E	Breast Tissue	100	<0.2	<0.05	0.003	<0.1	<0.3
		Liver	41	<0.2	11	0.036	<0.1	0.5
		Kidney	48	<0.2	0.16	0.024	0.3	0.4

^aMetal concentrations not determined for tissues from these geese.

Table A-2. Metal concentrations in ORR road-killed Canada geese tissues.

Goose Identification	Tissue/ Organ	Ag μg/g	Cd μg/g	Hg μg/g	Pb μg/g	Se μg/g	Cr μg/g
Y1 ^a	Tissue ^b	<0.20	0.05	0.009	<0.10	<0.30	<0.50
	Kidney	<0.20	<0.05	.059	<0.10	0.70	<0.50
X3 ^c	Tissue	<0.20	0.03	<0.001	0.50	0.30	N.A. ^c
	Liver	<0.20	0.46	0.004	0.40	0.90	N.A.
CC65 ^e	Tissue	<0.20	0.05	0.002	0.10	0.40	N.A.
	Liver	<0.20	0.22	0.003	0.40	0.70	N.A.
K54 ^f	Tissue	<0.20	0.10	0.003	0.20	0.50	<0.50
	Liver	<0.20	0.91	0.026	1.8	1.5	N.A.
	Kidney	<0.20	2.8	0.029	0.90	1.0	<0.50
K10 ^f	Tissue	<0.20	0.05	0.003	0.30	0.30	<0.50
K1 ^f	Tissue	<0.20	0.24	<0.001	0.50	0.30	<0.50
X4 ^c	Tissue	<0.20	0.008	0.002	0.30	0.40	N.A.
PS19	Tissue	<0.20	<0.05	<0.001	<0.10	0.40	N.A.
	Liver	<0.20	<0.05	0.004	<0.10	0.50	N.A.
	Kidney	<0.20	0.05	0.006	0.10	0.90	N.A.

^aCanada goose found at the Y-12 Plant.

^bTissue = Breast tissue

^cCanada goose found at ORNL.

^dN.A. = Not analyzed.

^eCanada goose found at Clark Center Park.

^fCanada goose found at ORGDP.

^gCanada goose found at a local community college.

VITA

Alicia Eileen Waters was born in Hagerstown, Maryland on March 6, 1965. She attended elementary schools in that area and graduated from Smithsburg High School in June 1983. That following September she entered Maryville College, and in May 1987 she received a Bachelor of Arts degree with honors. She had a major in Biology and a minor in Chemistry. From May 1987 to March 1988 she was employed by Martin Marietta Energy Systems. In March 1988 she entered the Graduate Program in Ecology at The University of Tennessee, Knoxville to begin study toward a Master's degree. She conducted her research at the Oak Ridge National Laboratory, Environmental Sciences Division. This degree was awarded in August 1990.

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