SITUATION REPORT: HEAVY DDT CONTAMINATION AT WHEELER NATIONAL WILDLIFE REFUGE

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Abstract: A DDT manufacturing plant that operated on the Redstone Arsenal near Huntsville, Alabama discharged DDT-laden effluent from 1947 to 1970 into a creek on Wheeler National Wildlife Refuge. Seven to 9 years after the plant closed, high DDT, DDE, and DDD levels were reported in soils, river sediments, and fish in the area. Eleven of 27 mallards *(Anas platyrhynchos)* collected on the Refuge during February 1979 had carcass DDE residues that exceeded levels associated with eggshell thinning. DDE residues in a smaller number of mallards exceeded levels associated with egg breakage, poor hatchability, and abnormal behavior and poor survival of offspring. Several avian species have disappeared from the Refuge since 1950, probably due to both industrial discharges of DDT from the plant and insecticidal use of DDT in the area. The contamination still presents a threat to herons, waterfowl, and raptors including occasional wintering or migrant eagles *(Haliaeetus leucocephalus)*, and probably many other avian species. A maternity colony of endangered gray bats *(Myotis grisescens)* is also threatened by this contamination.

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This report documents the existence and history of heavy DDT contamination in northern Alabama. The contamination originated on the Redstone Arsenal near Huntsville, at a DDT (1,1,1-trichloro-2,2-bis(p-chlorophenyl)ethane) manufacturing plant operated principally by Olin Chemical Company. The area of heaviest contamination is of particular concern because it encompasses Wheeler National Wildlife Refuge (NWR), which in recent years wintered about 40,000-60,000 ducks and 30,000 geese. The magnitude of DDT contamination on Wheeler NWR and surrounding area remains alarmingly high and probably has contributed to the decline of many avian species in the region. Recent studies of DDE residues in wildlife from Wheeler NWR indicate that the contamination is continuing to have an adverse impact on wildlife. In addition, concern has been expressed for the health of persons that consume fish (U.S. Public Health Service, 1980) and game animals from this area.

Dave Harris, U.S. Army Missile Readiness Command, Public Affairs Office, Redstone Arsenal, provided the information on the history of DDT production at the Arsenal. Kenneth L. Stromborg, William H. Stickel, and Thomas J. O'Shea provided a technical reviews of the manuscript.

PROPERTIES OF DDT

The organochlorine insecticide DDT is fairly persistent in the environment but can be broken down by living and physical systems to DDE and DDD. DDT, DDE, and DDD are not highly toxic to birds, ranking only as Class III (LC^{50} = 201-1000 ug/g[1]) and IV (LC^{50} = 100-5000 ug/g) in short term toxicity tests, where Class I chemicals are highly toxic and Class V chemicals are practically non-toxic (Hill et al. 1975). However DDT and DDE have

[1]ug/g = ppm

contributed to the decline of many avian species, particularly raptors, by affecting eggshell thickness and therefore resistance to egg breakage. DDE fed to black ducks (*Anas rubripes*) at a relatively low level (3 ug/g on a wet weight basis in the feed) caused shell thinning which persisted for 2 years after ducks were again fed control diets (Longcore and Stendell 1977). DDE is the metabolite primarily responsible for shell thinning.

In general, DDE is more stable than DDT and DDD. In a study of DDT-treated field plots (Beyer and Gish 1980), the half lives of p,p' and o,p' DDT (DDT isomers) in the soil were 2.0 and 2.3 years, respectively. DDD was only occasionally detected in the soil even though it is a major breakdown product of DDT. DDE concentrations increased during the first years after DDT application because DDE is a metabolite of DDT, and decreased only slightly from these higher levels during the following years. Due to its slow rate of degradation, Beyer and Gish (1980) were not able to calculate a half-life for DDE. The half life of DDD in earthworms in these plots was 1.6 years, but again DDE decreased only slightly with time (Beyer and Gish 1980). The persistence of DDE leads to its dominance in field samples.

HISTORY OF DDT AT REDSTONE ARSENAL

In 1947 the Calabama Chemical Company began manufacturing DDT in a plant on the Redstone Arsenal. The plant was leased from the Army and previously had been used for making components of Lewisite, an arsenic based gas produced during World War II. Olin Chemical Company bought Calabama in 1954 and manufactured DDT at the plant until 30 June 1970.

At full capacity about 1.13×10^7 kg of DDT, were produced at the plant annually. DDT was made by combining monochlorobenzene and chloral under heat and pressure. A solidified DDT product was produced with a purity of 99.9%. This crystaline DDT was ground, diluted with inert materials, and bagged at the plant and at other sites on the Arsenal and sold for insecticidal use. In manufacturing, the DDT was washed twice with water. About 5.68×10^6 l daily of waste water containing DDT flowed through a 1 km long open ditch. The ditch entered Huntsville Spring Branch downstream from the City of Huntsville. Part of the DDT effluent ditch and Huntsville Spring Branch are on Wheeler NWR (Fig. 1).

In the mid 1960's, several steps were taken to reduce the amount of DDT entering Huntsville Spring Branch. A settling pond was constructed at the head of the ditch in 1965. A new ditch and settling pond were constructed in 1967 and the old ditch was filled and treated with lime and ferrous sulfate to speed the degradation of the DDT. Effluent control devices were also installed in 1967. More stringent effluent standards were placed on the plant as production continued.

In 1969 the Department of Health, Education, and Welfare announced a multi-agency agreement to eliminate practically all use of DDT in the United States within 2 years. Less than 3 months later, the President issued an Executive Order giving all federal agencies 3 years to stop polluting the water and air. In 1970, the National Audubon Society, the National Wildlife Federation, and the Environmental Defense Fund filed suit in Federal Court charging Olin Mathieson Chemical Company with polluting Wheeler NWR with DDT. The company voluntarily stopped production of DDT at the plant on 30 June 1970. An attempt was made to manufacture methoxychlor [1,1'-(2,2,2-trichloroethylidene) bis(4-methyoxybenzene)] at the plant, but a cease-and-desist order was issued by the U.S. Army on 18 January 1971 and the lease for the manufacturing site was terminated on 1 April 1971.

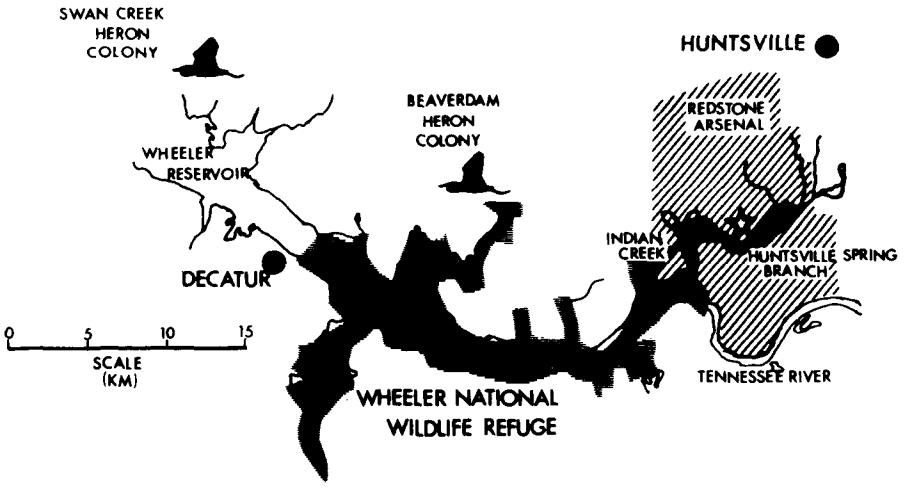

Fig. 1. Location of the DDT manufacturing plant (star), Redstone Arsenal, Alabama.

The plant was torn down in 1972. At the recommendation of the Federal Water Pollution Control Administration, the site was treated with lime and ferrous sulfate and covered with clay. The Army Environmental Hygiene Agency examined the area in 1977 and found that the DDT had not degraded to the extent anticipated and that DDT was present in soil, water, and fish on the Arsenal. This finding generated renewed interest in the DDT problem at the Arsenal and led to efforts to prevent DDT from being leached from the former manufacturing plant. In 1979, an activated carbon water treatment system was put into operation to remove DDT escaping from the site in drainage water. As a final step in the cleanup of the production site, two state-approved hazardous waste landfills were constructed and all known concentrated deposits of DDT on the Arsenal were buried in them. This operation involved excavating tons of earth and sediment from the factory site, drainage ditch, and several other sites where DDT waste had been dumped. Monitoring wells were drilled around all sites where DDT was found. The cost of the cleanup and containment actions on Army property was about $1.5 million.

In the spring of 1979, the U.S. Army agreed to study possible corrective actions to reduce the DDT-contamination on properties adjoining the Arsenal. The study was conducted by the U.S. Army Corps of Engineers and was directed at managing the DDT in the sediments of Huntsville Spring Branch on Wheeler NWR. The Tennessee Valley Authority (1978) had estimated that 3.63×10^6 kg of DDT were in the sediments of a 3.8 km stretch of Huntsville Spring Branch on refuge property. This estimate was revised to 7.3×10^5 kg based on the U.S. Army Corps of Engineers study (1980). The U.S. Army Corps of Engineers' study was in a preliminary form in September 1980 and should be completed by November 1980 at a cost of about $1.25 million.

SITE DESCRIPTION

Wheeler NWR and the Redstone Arsenal lie in the Tennessee River Valley near Huntsville. Decatur clay and alluvial soils predominate in the region. The Refuge is superimposed on parts of Wheeler Reservoir and surrounding lands and stretches 32 km along the Tennessee River. The Refuge covers about 13,972 ha including about 2430 ha of agricultural fields and 810 ha of seasonally flooded waterfowl reservoirs on which wildlife food crops are grown during the summer. Upland habitats support hardwood and pine forests.

The Redstone Arsenal has a longstanding agreement to use about 2835 ha of Refuge land that is now incorporated in the Arsenal boundries. This area of joint management is predominately along Huntsville Spring Branch and Indian Creek. These creeks are meandering, relatively slow moving, shallow, and have mud banks. Their banks are not well defined in many places and creek waters intermittently spread out into mud flats, swamps and hardwood bottomlands, creating ideal waterfowl habitat. Near the Tennessee River, Indian Creek has better defined banks and fewer areas of mud flats. However, the entire Huntsville Spring Branch-Indian Creek embayment overflows into surrounding hardwood bottomlands during periods of high water. There are no wildlife food plantings in this area of the Refuge.

DDT RESIDUES IN WILDLIFE

The U.S. Fish and Wildlife Service has collected residue data on several species at Wheeler NWR. In 1964, mean muscle and fat ΣDDT (combined total of DDT, DDE, and DDD) residues[2] respectively, for wildlife species collected near the intersection of the DDT effluent ditch and Huntsville Spring Branch were: cottontail rabbits *(Sylvilagus floridanus)*, 0.70 and 22; swamp rabbits *(S. aquaticus)*, 0.25 and 18; and crows *(Corvus brachyrhynchos)*, 46 and 860. In 1979, 9 years after the DDT plant was closed, these collections were duplicated. The ΣDDT residues in 1979 were similar to those in 1964. Mean ΣDDT muscle and fat residues in 1979 were: cottontail rabbits, 0.21 and 18.0; swamp rabbits, 0.15 and 18.0; and crows 12 and 309 ug/g (O'Shea et al. 1980). In 1979, these ΣDDT residues in rabbits were about 18 times higher on a lipid-weight basis[3] than those reported for rabbits in insecticide-treated soybean fields in Alabama (Causey et al. 1972). Residues in crows were also very high when compared with carcass residues of 0.62 ug/g ΣDDT found in crows from South Dakota (Greichus et al. 1978).

The U.S. Fish and Wildlife Service has participated since 1965 in the National Pesticide Monitoring Program which was set up to monitor changes and regional trends in nationwide pesticide residues. Waterfowl wings from the waterfowl harvest surveys have been analyzed and used as indicators of pesticide residue trends. Duck wings from Alabama consistently have shown high levels of DDT and its metabolites when compared with national averages. Mallard wings from Alabama had the highest average DDE residues of all states in the 1965-66 and 1969-70 surveys (Heath 1969, Heath and Hill 1974). In 1972, duck wings from Alabama had 12.9 times the national average of DDT and 6.2 times the national average of DDE (White and Heath 1976). In 1976-77, wings from Alabama again had the highest DDT residues and higher than average DDE residues (White 1979).

Wings from Alabama were analyzed for DDT residues on a county-by-county basis for the 1978-79 season (Fleming and O'Shea 1980). Only 2 counties from which wings were available had noticeably high DDT and DDE residues (Fig. 2). These 2 counties (Limestone and Madison) were 2 of the 3 counties that encompassed Wheeler NWR. For the years sampled in the national duck wing monitoring surveys, 28-50 percent of the wings submitted to the waterfowl harvest survey came from the 3 counties encompassing the Refuge. This indicated that a significant portion of Alabama's waterfowl harvest and wintering waterfowl concentrations occurred near Wheeler NWR. In addition, it showed that ducks from these counties were so contaminated that they influence the mean statewide wing residue concentration.

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[2]All residues are expressed in ug/g on the basis of the wet weight of the sample unless stated otherwise. Where possible, residues are reported to 2 significant digits based on analytical capabilities.

[3]Residues expressed as ug/g of body lipids.

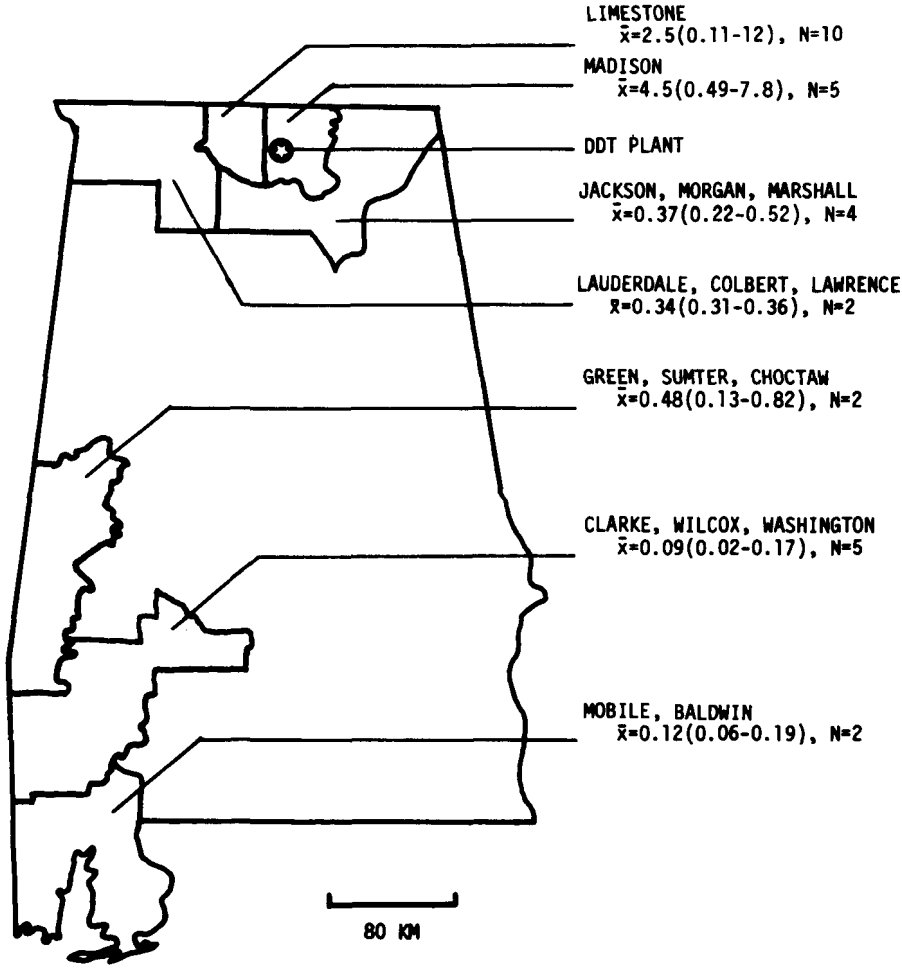

Fig. 2. Combined DDT, DDE, and DDD residues (ug/g) in mallard wings from Alabama during the 1978-79 waterfowl season. Wings were combined into sample pools of 5 wings each for analyses. The numbers in parentheses are the ranges of the residues observed.

In mid-February 1979, mallards were collected from Huntsville Spring Branch about 500m downstream from the entrance of the DDT effluent ditch. Mallards were shot as they entered the area to feed and roost for the night. Residue levels in carcasses of these ducks ranged from $<$ 0.05 to 480 ug/g DDT; the geometric mean was 4.0 ug/g. The bird with the highest carcass residue (480 ug/g) was an immature female (O'Shea et al. 1980). Estimates of waterfowl numbers at Wheeler NWR indicated that spring migration was underway at the time collections were made. It is likely, therefore, that this sample was biased toward low residue values because of the influx of mallards that did not winter at Wheeler NWR. In view of this possible bias, mallards were collected in January 1980 and will be analyzed for organochlorines.

In July and August 1979, young (60-120 days old) wood ducks *(Aix sponsa)* were collected from 5 sites on Wheeler NWR and at sites 145 km upstream and 50 km

downstream from Indian Creek's confluence with the Tennessee River. ΣDDT residues in duck carcasses collected in Huntsville Spring Branch were higher than at other sites ($\bar{x}$ = 3.5 ug/g) and averaged 58 times higher than the mean residues found in samples collected at the upstream site near Scottsboro, Alabama ($\bar{x}$ = 0.06 ug/g). In general, residue levels varied inversely with the distances from Huntsville Spring Branch. In August and September 1979, 10 addled wood duck eggs from Wheeler NWR were collected and analyzed. Residues of ΣDDT ranged from 0.16 to 5.4 ug/g (Fleming and Cromartie 1981).

Fish samples from the Tennessee River near its junction with Indian Creek have ΣDDT residues that frequently exceed the tolerance of 5 ug/g (in fat) established by the Food and Drug Administration for human food. In a study conducted by the U.S. Army (U.S. Army Environmental Hygiene Agency 1977), DDT levels in commercial and sport fish were as high as 410 ug/g wet weight. Residues in fat would have been several times higher.

EFFECTS OF DDT ON WILDLIFE IN NORTHERN ALABAMA

The effects of the DDT contamination on resident mammals on the Refuge have not been determined, but there is no indication that rabbits, beaver *(Castor canadensis)* and deer *(Odocoileus virginianus)* have been adversely affected. In February 1979, swamp rabbits and cottontails were very abundant between the former DDT plant site and Huntsville Spring Branch. Beaver sign was plentiful, even in some of the containment ditches around the DDT plant site. Hunter harvest of deer and cottontail and swamp rabbits on the Refuge portion of the Arsenal have not indicated serious declines in these species. Data are not available for omnivorous and carnivorous mammals except for bats which will be mentioned later.

The effects of DDT and its metabolites on birds, both as a result of discharge from the manufacturing plant and insecticidal use in the area, have been obvious in certain species, and less obvious, though possibly significant, in other species. The following estimates of population numbers were based on observations by personnel at Wheeler NWR and additional data from Refuge files. Double-crested cormorant *(Phalacrocorax auritus)* numbers were estimated at about 10,000 during cold weather months of the late 1930's through the late 1940's. Beginning about 1950, cormorants virtually vanished from the refuge; only rarely were sightings reported through the 1950's, 1960's and most of the 1970's. Small numbers of these birds began to return to the Refuge in the late 1970's; 35 were present during the winter of 1979-80.

Wading birds appear to have been severely affected. A large nesting colony of great blue herons *(Ardea herodias)*, and great egrets *(Casmerodius albus)* was first recorded on the Refuge in 1940 in Beaverdam Swamp and grew to an estimated 500 nests by 1950. Anhingas *(Anhinga anhinga)* also nested in this colony. Beaverdam Swamp was aerially sprayed with DDT in the springs of 1950 and 1951 by the Tennessee Valley Authority to control mosquitoes. Refuge records indicate that 250-300 common egret and 250-300 great blue heron nests with young were present on April 11, 1950, before spraying. Shortly after the spraying, many dead young were found and the great egrets abandoned the colony. The great blue herons returned in 1951, but only 80 active nests were present and several dead herons and two dead black vultures *(Coragyps atratus)* were found after a 1951 spraying with DDT. The great blue herons abandoned the colony in 1951. There are no records of these great blue herons, great egrets, or anhingas nesting on the Refuge since that time. Although mosquito spraying was a major factor in the loss of this heron colony, high environmental contamination from industrial DDT effluent probably contributed to the decline and could have limited recovery of the nesting colonies of these three species after termination of the spraying program.

In 1960, a mixed nesting colony of little blue herons *(Florida caerulea)* and black-crowned night herons *(Nycticorax nycticorax)*, great egrets, cattle egrets *(Bubulcus ibis)* and snowy egrets *(Leucophoyx thula)* was discovered on the Swan Creek State Manage-

ment Area, just west of the Refuge. By 1964, nesting at this site had increased to 95 occupied nests. The colony dwindled to 50 nests in 1965 and then was abandoned. There has been no heron or egret nesting throughout this entire locality since that time, except for a few nestings by green herons *(Butorides virescens)* and occasional small colonies of yellow-crowned night herons *(Nycianassa violacea)*. All wading birds except wintering great blue herons were extremely rare for a 10-year period from the mid-1960's to the mid-1970's. There has been a slight increase in wading bird use of the Refuge during the past 3 summers. Great blue herons continue to be numerous on the Refuge in winter.

Anhingas were once fairly common summer residents and occasionally nested on the Refuge. But anhingas have not been sighted on the Refuge since 1950. Bald eagles *(Haliaeetus leucocephalus)* once nested on the Refuge, but have not done so since 1947. Throughout the 1950's, 10 to 12 eagles used the refuge regularly during the winter. Now, there are only a few transient eagles during the winter. Peregrine falcons *(Falco peregrinus)* once nested in the vicinity of the Refuge and were fairly common throughout the winter. They vanished from the Refuge throughout the 1960's and early 1970's, though there are now rare sightings during fall and winter. Both turkey *(Cathartes aura)* and black vultures were once common. There was a large vulture roost on the Refuge that was estimated to hold about 1,000 vultures during the 1940's and early 1950's. These birds virtually vanished, except for a few transient turkey vultures, from the late 1950's through the early 1970's. They have reappeared in small numbers during the past 3 years. Red-shouldered hawks *(Buteo lineatus)* were originally the most common warm weather hawk on the Refuge. Spring and summer numbers were estimated at about 70. Beginning in the late 1950's, these hawks almost vanished and are still very rare. Barred owls *(Strix varia)* were once common throughout the wooded bottoms of the Refuge; numbers were estimated at 60. As with some other raptors, these almost disappeared from the mid-1950's to the mid-1970's, but seem to be recovering within the past 3 or 4 years; present numbers are estimated at a dozen. There were reductions among other bird species, especially eastern bluebirds *(Sialia sialis)*, common night hawks *(Chordeiles minor)*, and flycatchers (Tyrannidae), that may well have been due to DDT contamination.

We do not have enough data to totally evaluate the impact of DDT from the Arsenal on waterfowl. One problem is determining the number of birds that may be receiving a significant exposure. As many as 90,000 ducks and geese winter at the Refuge. Surrounding areas of the Tennessee River also are excellent waterfowl wintering habitat. Wintering waterfowl populations probably intermix freely and at times use parts of the entire region around the Refuge, which means that the number of individual birds using the Refuge and possibly being exposed to the high DDT contamination might be much higher than the number of birds counted on the Refuge on any 1 day. Wing residue survey data (Fleming and O'Shea 1980) support this hypothesis. A significant number of ducks from the counties encompassing the Refuge, though not on the Refuge at the time of their collection, had higher than background levels of DDT and DDE.

Carcasses of some mallards from Huntsville Spring Branch had up to 480 ppm ΣDDT (O'Shea et al. 1980). Under the right conditions of food deprivation, energy depletion, and other stresses, high levels of carcass DDT could be mobilized to the brain, resulting in mortality (Van Velzen et al. 1972).

In laboratory studies, black ducks continuously fed a diet containing 3 ug/g DDE, beginning 3-4 months before the reproductive season, had carcass residues averaging 160 ug/g DDE and laid eggs with shells 20 percent thinner than those of controls. Carcass residues had decreased to 3.4 ug/g 2 years after these ducks were taken off DDE treated feed. However, eggshells after this 2 year period were still 10 percent thinner than those from controls (Longcore and Stendell 1977). Black ducks fed diets containing 3 ug/g DDE, and allowed to incubate their own eggs, had a 42 percent egg breakage rate compared with 6 percent for eggs from controls. Thinning of these broken eggs averaged 22 to 33 percent,

depending on what portion of the shell was measured (Longcore and Samson 1973). Of the mallards from Huntsville Spring Branch in 1979, 41 percent had residue levels that exceeded 3.4 ug/g and 11 percent exceeded 100 ppm. As stated previously, the incidence and magnitude of these residues are probably biased toward the low side. Productivity and survival of ducks contaminated by the high DDT and DDE levels in the Huntsville Spring Branch-Indian Creek embayment and surrounding areas might be adversely affected by this contamination for at least 2 years, even if they wintered in uncontaminated areas in subsequent years. Embryo mortality was higher in eggs from black ducks fed diets containing 3 ug/g DDE than in eggs from controls. Survival of ducklings from parents fed diets containing 3 ug/g DDE was also lower (Longcore et al. 1971). Abnormal behavior of the young from DDE-fed parents has also been noted (Heinz 1976).

The overall effects of DDT compounds on waterfowl cannot be determined precisely. Banding records show that mallards that winter in northern Alabama do not have a common breeding ground but come from several Canadian Provinces and several northern states. Thus it is not feasible to study the actual effects of this contamination on reproductive success of waterfowl that have wintered at Wheeler NWR. It is clear, however, that the contamination exceeds levels known to affect reproduction in ducks experimentally fed DDE. Most of the ducks that use the Refuge are dabbling ducks. The carnivorous nature of many diving ducks and mergansers, in association with the potential for DDT and DDE to bioaccumulate through the food chain, would put them in even greater peril than dabbling ducks.

The Refuge harbors a maternity colony of the endangered gray bat *(Myotis grisescens)*. Dead young collected from beneath the colony had 19 to 35 ug/g DDE and 4 to 21 ug/g DDD in their carcasses, but by themselves, these concentrations were not high enough to have caused the mortality (D. R. Clark personal communication, Patuxent Wildlife Research Center, Laurel, MD). Residue levels did indicate that the bats were contaminated with potentially harmful amounts of DDT compounds.

THE OUTLOOK

The present level of DDT contamination in the area of Wheeler NWR poses a continuing threat to raptors, waterfowl, herons, gray bats, and other species. The outlook for improvement is bleak considering the high degree of contamination and the persistence of DDT and DDE. The U.S. Army Corps of Engineers is studying the feasibility of taking corrective engineering actions. Alternatives under consideration include dredging and/or filling portions of Huntsville Spring Branch and diverting the creek around the areas of heaviest contamination. Although these options may slow transport of DDT down river, their beneficial aspects for wildlife are yet to be determined. At the present time, the Huntsville Spring Branch-Indian Creek Embayment appears to be the major area where waterfowl acquire their high levels of DDT and DDE. This embayment is good waterfowl and waterbird habitat. The natural attractiveness of this habitat will continue to draw waterbirds and wintering waterfowl to the area of heaviest contamination. Although 95-99 percent of the DDT in the creek may be removed or made unavailable by corrective measures, the amount of DDT remaining in the creek may still be sufficient to have adverse effects on wildlife.

LITERATURE CITED

BEYER, W. N. and C. D. GISH. 1980. DDT, dieldrin, and heptachlor in earthworms during eleven years after application and resultant hazards to birds. J. Appl. Ecol. (in press).

CAUSEY, K., S. C. McINTYRE, Jr., and R. W. RICHBURG. 1972. Organochlorine insecticide residues in quail, rabbits, and deer from selected Alabama soybean fields. J. Agr. Food Chem. 20:1205-1209

FLEMING, W. J. and E. CROMARTIE. 1981. DDE contamination of young wood ducks on Wheeler National Wildlife Refuge, Alabama. Pest. Monit. J. 14:115-118.

_____ and T. J. O'SHEA. 1980. Influence of a local source of DDT pollution on state wide DDT residues in waterfowl wings: an example from Alabama. Pest. Monit. J. 14:86-89.

GREICHUS, Y. A., B. D. GUECK, and B. D. AMMANN. 1978. Organochlorine insecticide, polychlorinated biphenyl, and metal residues in some South Dakota birds, 1975-76. Pestic. Monit. J. 12:4-7.

HEATH, R. G. 1969. Nationwide residues of organochlorine pesticides in wings of mallards and black ducks. Pestic. Monit. J. 3:115-123.

_____ and E. F. HILL. 1974. Nationwide organochlorine and mercury residues in wings of adult mallards and black ducks during the 1969-70 hunting season. Pestic. Monit. J. 7:153-164.

HEINZ, G. H. 1976. Behavior of mallard ducklings from parents fed 3 ppm DDE. Bull. Environ. Contam. Toxicol. 16:640-645.

HILL, E. F., R. G. HEATH, J. W. SPANN, and J. D. WILLIAMS. 1975. Lethal dietary toxicities of environmental pollutants to birds. U.S. Fish and Wildlife Service, Special Scientific Report-Wildlife No. 191. 61pp.

LONGCORE, J. R., and F. B. SAMSON. 1973. Eggshell breakage by incubating black ducks fed DDE. J. Wildl. Manage. 37:390-394.

_____ and T. W. WITTENDALE, JR. 1971. DDE things eggshells and lowers reproductive success of captive black ducks. Bull. Environ. Contam. Toxicol. 6:485-490.

_____ and R. C. STENDELL. 1977. Shell thinnings and reproductive impairment in black ducks after cessation of DDT dosage. Arch. Environ. Contam. Toxicol. 6:293-304.

O'SHEA, T. J., W. J. FLEMING, and E. CROMARTIE. 1980. DDT contamination at Wheeler National Wildlife Refuge. Science 209:509-510.

TENNESSEE VALLEY AUTHORITY. 1978. DDT residues in sediment and fish in the vicinity of Redstone Arsenal, Alabama. Chattanooga, Tenn. 11pp.

U.S. ARMY CORPS OF ENGINEERS. 1980. Engineering and environmental study of DDT contamination of Huntsville Spring Branch, Indian Creek, and adjacent lands and waters, Wheeler Reservoir, Alabama. Preliminary Report, August 1980.

U.S. ARMY ENVIRONMENTAL HYGIENE AGENCY. 1977. Evaluation of environmental degradation from prior DDT waste disposal at Redstone Arsenal, Alabama, 20-25 June 1977. Water Quality Engineering Special Study No. 24-0044-78.

U.S. PUBLIC HEALTH SERVICE. 1980. Cross-sectional study of a community with exceptional exposure to DDT: Triana, Alabama. EPI-79-44-3.

VAN VELZEN, A. C., W. B. STILES, L. F. STICKEL. 1972. Lethal mobilization of DDT by cowbirds. J. Wildl. Manage. 36:733-739.

WHITE, D. H. 1979. Nationwide residues of organochlorine compounds in wings of adult mallards and black ducks, 1976-77. Pestic. Monit. J. 13:13-16.

_____ and R. G. HEATH. 1976. Nationwide residues of organochlorines in wings of adult mallards and black ducks, 1972-73. Pestic. Monit. J. 9:176-185.