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POTENTIAL HEALTH EFFECTS FROM PERSISTENT ORGANICS IN WASTEWATER AND SLUDGES USED FOR LAND APPLICATION

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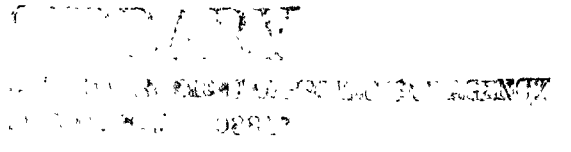

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our national environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The primary mission of the Health Effects Research Laboratory in Cincinnati (HERL) is to provide a sound health effects data base in support of the regulatory activities of the EPA. To this end, HERL conducts a research program to identify, characterize, and quantitate harmful effects of pollutants that may result from exposure to chemical, physical, or biological agents found in the environment. In addition to the valuable health information generated by these activities, new research techniques and methods are being developed that contribute to better understanding of human biochemical and physiological functions, and how these functions are altered by low-level insults.

This report provides a general assessment of the potential problems which may occur when persistent organics contained in municipal sludges are applied to land. Since information on this subject is sparce, examples of problems which might occur if organic concentrations are excessive are drawn from other sources such as refuse. With a better understanding of any health effects, measures can be developed to reduce exposure to potentially harmful materials.

R. J. Garner
Director
Health Effects Research Laboratory

ABSTRACT

The potential health problems associated with the presence of persistent organic chemicals in wastewater and sludge, when applied to agricultural lands, are reviewed. The type and amounts of organic chemicals present in wastewater and sludge, their fate on land, and available control measures are discussed. The potential health effects of organic chemicals on workers/populations who come in contact with them during wastewater treatment, transportation, and/or application are considered. Examples are given from known cases of acute exposure - Louisville, Kentucky; Memphis, Tennessee; Bloomington, Indiana; Toone-Teague, Tennessee; Love Canal, New York; etc., since there is no direct information available on effects of long-term exposure to organic chemicals in wastewater and sludge applied to agricultural land.

The effects of organic chemicals on the quality of ground and surface waters and on the food chain including the uptake by plants, animals, and humans are also considered. Examples are cited from known cases of ground and surface water contamination from leachates from chemical waste landfills and from industrial waste discharges. For the effect on the food chain, the Japanese incident of rice oil contamination by PCBs and the accidental dairy cattle feed contamination by PBBs in Michigan are reviewed. It is emphasized that the examples cited represent effects of acute exposure and, therefore, may not be representative of potential contamination by organic chemicals of food chains from land application. It is believed that they might serve the purpose of providing some insight into the effect of consuming low levels of these chemicals through food chains over a long period of time.

The review concludes that there is not sufficient information at present to assess the full extent of long-term health risks of exposure to organics in the wastewater treatment plants or at land application sites. Recommendations are made concerning guidelines and further research. Further research is recommended on the uptake of organic chemicals by food crops. It is also recommended that health surveys be carried out on populations that are known to have consumed food grown on land application facilities. Long-term follow-up is also recommended for populations who have had acute short-term exposure to organic chemicals from waste materials.

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SECTION 1

INTRODUCTION

Among all constituents of concern that are present in wastewaters and sludges, the effects of the toxic organic chemicals are the least known. Of the chemical contaminants, heavy metals and persistent organic compounds are of most concern. Most attention has been paid to the fate and effect of heavy metals, little to the impact of persistent organic compounds. Since many heavy metals and organic chemicals will be in more concentrated form in sludge than in wastewater, the latter may be considered less hazardous than sludge, but there may be exceptions. The potential problems that may be caused by persistent organic compounds to the workers/populations who come in contact with them during wastewater treatment, transportation, and/or application; their effects on the food chain, on the quality of ground and surface waters; and recommendations for the regulation of them will be considered in this report.

Little information is available on direct health effects of organic chemicals in wastewater and sludge applied to land. Examples of known health effects on wastewater treatment plant workers from acute exposure to toxic organic chemicals are included where applicable. Similarly, since there is no information available on groundwater and surface water pollution from organic chemicals in wastewater and sludge applied to land, effects of toxic organic chemicals leaching from industrial chemical waste landfills are discussed briefly because of their potential for groundwater pollution.

The reports of Jones and Lee (1), Dacre (2), Lennette and Spath (3), Chang and Page (4), and Braude (5) form the background materials for parts of this report.

In order to assess the potential health risks of the organic chemicals in wastewaters and sludge for the practice of the various forms of land application and disposal, a number of factors need to be understood:

(1) The type and amounts of the organic compounds present in wastewaters and sludge;

(2) Their fate and potential environmental contamination;

(3) Available control measures; and

(4) Their effects on wastewater treatment plant workers, on populations living near land application facilities, on ground and surface water pollution, and on the food chain.

SECTION 2

CONCLUSIONS

At present there is not sufficient information to assess the long-term health risk associated with exposure to organics in the wastewater treatment plants or at land application sites. Acute toxic effects are readily recognizable. The harmful effects thereof can be most directly reduced by enforcement of appropriate pretreatment requirements. If these are not effective, harmful effects can possibly be reduced by removal of workers from the source of toxic fumes, by proper ventilation and by the use of appropriate respirators and protective clothing, etc., since the exposure to organic chemicals is mainly by inhalation. Effects of exposure to low levels of organics over a long period of time (chronic exposure) including dose-response relationships and health effects are not known at this time.

Land application systems tend to concentrate chemicals in the soil enhancing the possibility of uptake by plants and animals. If more complete information on the concentration and fate of the organic chemicals in the environment (water, air, food crops, animals, etc.) were known, it would be possible to make an assessment of the potential hazards associated with the land disposal of wastewaters and sludges containing hazardous organic chemicals. At the present time, sufficient information is not available to do this.

The potential for groundwater pollution from leaching of waste landfills is a serious problem and adequate preventive measures should be instituted. The potential for air pollution from landfills that have received a variety of substances which may interact with each other has been given very little attention.

SECTION 3

RECOMMENDATIONS

POLICY/GUIDELINES

(1) Pretreatment standards for the discharge of industrial wastes to municipal sewerage systems should take into account downstream uses of the receiving body of water such as for crop irrigation; the nature of the specific municipal wastewater treatment processes; the type of industrial waste; and the prevalence of combined sewer discharges.

(2) Unless adequate pretreatment requirements are being enforced, land application of wastewater or sludge containing relatively high concentrations of hazardous contaminants should be limited to land not involved in food production because there is only very limited information available on the uptake of organic chemicals by vegetation.

(3) Sludges containing more than 10 ppm PCBs and/or significant amounts of other toxic organic chemicals should not be permitted to be applied on the surface of grazing lands since sludge may be ingested by animals and because of the tendency of many organics including PCBs to accumulate in lipid-rich tissues and milk.

(4) Sludges containing high levels of persistent organic compounds should not be used as animal feed supplement after disinfection alone.

(5) Wastes containing relatively high levels of persistent organic contaminants should be classified into categories such as: (1) those suitable to disposal in secure landfills, (2) those suitable only for destructive-type disposal because of their hazardous nature or potential to produce hazardous substances upon contact with other wastes, and (3) those suitable under certain conditions for land application.

FURTHER RESEARCH

(1) Uptake of organic chemicals by food crops should be studied in detail. Since very little is known about the organics uptake by plants, all parts of the plant should be studied. (Some selectivity regarding the parts of the plant can be exercised depending upon which parts of a given crop are edible.)

(2) Full extent of groundwater pollution by organic chemicals leaching from landfills and/or lands with buried sludge should be studied further.

(3) Long-term follow-up should be initiated on populations who have had acute short-term exposure to organic chemicals from waste materials. Examples of such populations are those associated with exposures at Love Canal, New York, Toone-Teague, Tennessee, and the Louisville, Kentucky, and Memphis, Tennessee, wastewater treatment plants.

(4) The potential health effects of utilizing domestic sewage sludge as a cattle feed supplement for both beef and dairy cattle should be studied further from the standpoint of organics passing through the food chain.

SECTION 4

CHARACTERIZATION OF ORGANIC CHEMICALS IN WASTEWATER AND SLUDGE

The presence of organic matter in raw and treated wastewater is highly variable and dependent upon the source of wastewater and the degree of treatment. Attempts to characterize organic matter in wastewaters in the past have not been very successful. It is only recently that the extensive identification of organic compounds in waters, drinking water in particular, has been undertaken. A summary listing of some 1000 organic compounds in effluent waters has been published by the World Health Organization (WHO) (6). Many of these organics have been identified in raw sewage. Some of these compounds are very toxic and some of them are known or suspected carcinogens as reviewed in a research report to Congress by the National Academy of Sciences, National Research Council (7). Chlorination of treated wastewater results in the formation of a wide range of chlorinated derivatives (8). Many of the organic chemicals present in wastewater are toxic and potentially carcinogenic, teratogenic, or mutagenic to humans. A relatively large number of organic compounds survive the conventional treatment process and are present in the treated effluent in the µg/l range. The sources of these compounds are difficult to trace except when there is an accidental spill such as from the local industrial plants.

In the past few years there have been significant efforts toward determining the nature and concentrations of the organic compounds present in wastewaters and sludges. Some work in this area has been devoted to chlorinated hydrocarbons, pesticides, and PCBs. EPA Office of Research and Development has been conducting a survey of chlorinated hydrocarbons in municipal wastewater effluents which showed the presence of chlorophenols, chlorobenzenes, chloralkanes, and chloroalkenes (9). Table 1 lists some of the organic compounds together with the range of concentrations found in municipal wastewater effluents (1,10,11). A number of new compounds have been found in the Muskegon untreated wastewaters in addition to some of the compounds identified by others (11) (Table 2). The concentration of chlorinated hydrocarbon pesticides and other organic compounds identified in several wastewater sludges are presented in Table 3 (1,12,13).

Sludges from Schenectady, New York, and Bloomington, Indiana, were found to contain 23.1 ppm (14) and 300 ppm (15) PCBs, respectively. General Electric Company in Schenectady, New York, and Westinghouse Electric in Bloomington, Indiana, both manufacture electrical capacitors in which PCBs are used as insulating fluids. Further, the sediments from Hudson River below Schenectady and other streams near Bloomington were found to be contaminated with PCBs (15,16). PCBs levels as high as 2980 ppm were found in

TABLE 1. RANGES OF CONCENTRATIONS OF ORGANIC COMPOUNDS IN MUNICIPAL WASTEWATER TREATMENT PLANT EFFLUENTS (1,10,11)[a]
(µg/l)

Compound \ Location & reference	Dayton, OH[b]		Cincinnati, OH[c]		Muskegon, MI[d]
	Unchlorinated	Chlorinated	Unchlorinated	Chlorinated	
Chloroform	0.3-1.4	0.4-12	0.1-0.7	0.5-12	1-13
Trichloroethylene	0.2-1.7	0.1-10	-	0.6-0.7	2-10
Benzidine	-	<0.1	-	<0.1	< 1
Vinyl Chloride	-	< 1	-	< 1	< 1
Benzene	-	0.2-40	-	0.3-3.8	<1-8
PCB's	-	< 1	-	-	< 10
Endrin	-	< 1	-	-	< 1
Toxaphene	-	< 1	-	-	< 50
Methanol	-	150-510	-	*	-
Ethanol	-	150-3000	-	*	-
Acetone	-	50-300	-	20-400	-
2,3-Dithiabutane	-	< 10	-	< 1	-
Carbon Disulfide	-	< 2	-	2-8	-
1,1,1-Trichloroethane	-	1-15	-	1	-
Tetrachloroethylene	-	1-20	-	0.3-3	-
Toluene	-	1-10	-	1	-
Xylene	-	1-15	-	10	-
Acrolein	-	20-200	-	10-150	-
Acetaldehyde	-	90-1350	-	100-560	-
Carbon Tetrachloride	-	3	-	*	-

(continued)

TABLE 1 (continued)

Compound \ Location & reference	Dayton, OH[b]		Cincinnati, OH[c]		Muskegon, MI[d]
	Unchlorinated	Chlorinated	Unchlorinated	Chlorinated	
Chlorodibromomethane	*	0.1	0.1	0.4-4.6	-
Dichlorobromomethane	0.1	0.1-0.4	0.1-0.3	0.1-8	-
Bromoform	*	0.1-0.3	*	0.2-0.3	-
1,3-Dichloroethane	1.4	0.1-4.6	*	*	-
Methylene Chloride	-	2-50	-	1-10	-

Dash (-) indicates no data found.

a. Reprinted from "Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges" with permission of B.P. Sagik and C.A. Sorber, Editors, The University of Texas at San Antonio, San Antonio, Texas (1978).

b. US EPA (10). Range of values for samples having concentrations above the detection limit in chlorinated and unchlorinated effluent from Dayton, OH secondary (trickling filter) sewage treatment plant, mixed domestic and industrial wastewaters. A single number (detection limit) or asterisk indicates that no measurable concentrations were found in 15-20 samples analyzed.

c. US EPA (10). Range of values for samples having concentrations in chlorinated and unchlorinated effluent from Cincinnati's Muddy Creek secondary (AS) sewage treatment plant; primarily domestic wastewater. A single number (detection limit) indicates that no measurable concentrations were found in the 15-20 samples analyzed.

d. US EPA, Robert S. Kerr Research Laboratory (11). Range of concentrations in five samples of effluent from spray irrigation wastewater disposal system in Muskegon, MI collected on five days in fall 1976.

TABLE 2. ORGANIC COMPOUNDS IDENTIFIED IN MUSKEGON SYSTEM WASTEWATER (11)

Pollutant[b]	Wastewater Sampled[a]			
	Influent	Aerated lagoon effluent	Holding lagoon effluent	Final effluent
Dichloromethane (c)	+	+	+	+
1,2-Dichloroethane (c)	+	+	+	-
1,2-Dichloroethylene (c)	+	+	-	-
Toluene	+	+	-	-
Xylene (d)	+	+	-	-
Acetone	+	+	+	+
Dimethyl sulfide	+	+	+	-
3-Pentanone	+	+	-	-
Dimethyl disulfide	+	+	-	-
Dichlorobenzidine (c)	+	+	-	-
Phenol (c) (d)	+	-	-	-
Ethylbenzene (c)	+	-	-	-
Trichlorobenzene (c)	+	-	-	-
Diazobenzene	+	+	+	-
Dichlorobenzophenone	+	+	+	-
Aniline (d)	+	+	?	-
N-Ethylaniline	+	-	-	-
N,N-Diethylaniline	+	-	-	-
N,N-Dimethylaniline (d)	+	+	+	-
Chloroaniline (d)	+	+	+	-
Benzothiazole	+	-	-	-
Benzyl alcohol (d)	+	+	-	-
Cresol (d)	+	-	-	-
Methoxy phenol (d)	+	-	-	-
Hydroxymethoxyacetophenone	+	+	+	-
Dimethoxyacetophenone	+	+	-	-
Chloropropiophenone	+	-	-	-
Hexanoic acid	+	-	?	-
Decanoic acid (d)	+	+	?	-
Dodecanoic acid	+	+	-	-
Tetradecanoic acid	+	?	+	-
Hexadecanoic acid	+	+	+	+
Heptadecanoic acid	+	+	-	-
Octadecanoic acid	+	+	+	-
α-Pinene	+	-	-	-
β-Pinene	+	-	-	-
α-Terpineol	+	-	-	-
Trithiapentane (d)	+	+	-	-
Tetrathiahexane (d)	+	+	+	-
2-Ethyl-1-hexanol	+	-	-	-
Isoborneol	+	+	-	-

(continued)

TABLE 2 (continued)

Pollutant[b]	Wastewater Sampled[a]			
	Influent	Aerated lagoon effluent	Holding lagoon effluent	Final effluent
Decanol	+	-	-	-
Dodecanol	+	+	-	+
Tetradecanol	+	-	-	+
2-(2-(2-ethoxyethoxy)ethoxy)ethanol	+	-	-	-
Tetradecene	-	+	-	-
Trimethylisocyanurate	-	-	+	+
Atrazine	-	-	-	+
Heptanoic acid (e)	-	(f)	+	-
Octanoic acid (e)	+	(f)	+	-
Nonanoic acid (e)	+	(f)	+	-
Pentadecanoic acid (e)	-	(f)	+	-
O-Phenyl phenol (e)	+	(f)	-	-
Benzoic acid (e)	+	(f)	+	-
Phenylacetic acid (e)	+	(f)	-	-
Salicylic acid (e)	+	(f)	-	-
Phenylpropionic acid (e)	+	(f)	-	-
Vanillin (e)	+	(f)	-	-
Acetovanillin (e)	+	(f)	-	-
Homovanillin (e)	+	(f)	-	-
2-(4-Chlorophenoxy)2-methyl propionic acid (e)	+	(f)	+	-

a. Presence or absence of pollutant in wastewater is indicated by + or - "?" indicates presence suspected but not confirmed beyond reasonable doubt.

b. Unless noted otherwise, listed compounds were identified in daily samples at RSKERL.

c. Compounds appearing on the EPA "List of Dangerous Pollutants."

d. Identified in both daily samples at RSKERL and composite samples at AERL.

e. Identified in composite samples at AERL.

f. Composite samples of aerated lagoon effluent were not obtained.

TABLE 3. CONCENTRATIONS OF ORGANIC COMPOUNDS IN DOMESTIC SLUDGES (1,12,13)[a]
µg/l LIQUID SLUDGE

Compound	North Toronto[b]	Point Edward[b]	Newmarket[b]	Sarnia[b]	MSDGC[c]
% Solids in sludge	6.25	6.90	12.2	16.19	
Chlorinated hydrocarbon pesticides and PCBs:					
pp'DDT	1.33	0.77	1.12	2.70	-
op'DDT	6.87	4.11	1.15	5.25	-
pp'DDE	7.18	3.68	2.18	20.77	-
pp'DDD	4.31	3.98	1.60	6.41	-
Total DDD/DDE/DDT	19.69	12.54	6.68	35.13	-
DDT	-	-	-	-	< 100
a-Chlordane	15.79	12.51	5.69	16.99	-
γ-Chlordane	12.56	11.41	2.84	12.92	-
Total chlordane isomers	28.35	23.92	8.53	29.91	< 10
Heptachlor	5.37	2.29	0.70	14.95	< 200
Heptachlor epoxide	3.04	1.77	0.58	6.78	< 200
Total heptachlor	8.41	4.06	1.28	21.73	-
Aldrin	2.03	1.09	0.70	9.40	< 10
Dieldrin	3.03	1.69	1.65	3.23	< 10
Lindane	1.48	1.16	0.63	3.22	< 500
Toxaphene	-	-	-	-	< 10
Total organochlorine pesticides	63	45	20	103	-
PCBs (Arochlor 1254)[d]	214	108	74	1122	-
Other pesticides and organics:					
Orthophosphates and carbamate insecticides	-	-	-	-	< 10
2,4-D	-	-	-	-	<1000
2,4,5-T	-	-	-	-	< 5
2,4,5-TP	-	-	-	-	< 30

Dash (-) indicates no data found (none detected).

a. Reprinted from "Risk Assessment and Health Effects of Land Application of Municipal Wastewater and Sludges" with permission of B.P. Sagik and C.A. Sorber, eds., The University of Texas at San Antonio, San Antonio, TX (1978).
b. Chawla et al. (12). Mean levels of organochlorine pesticides in digested chemical sludges in four Ontario treatment plants using lime (Newmarket), iron (North Toronto, Sarnia) or alum (Point Edward) treatment.
c. McCalla et al. (13). Concentrations in sludges from five sludge sources in the Metropolitan Sanitary District of Greater Chicago (MSDGC), solid content of the sludges unknown.
d. Mean monthly levels (12).

Hudson River sediment (17). PCB concentrations in sludges from 33 municipalities in Ontario, Canada, were surveyed by Shannon et al. (18). PCB levels in untreated wastewater ranged from <0.1 to 1.8 ppb, while the levels in digested sludge ranged from 0.6 to 76.6 ppm (dry weight). Municipal sludge in Hopewell, Virginia, was found to be contaminated by kepone, a chlorinated pesticide manufactured by Life Science Products which discharged kepone waste into the city sewage system (19). Kepone levels of 0.1 - 10 ppm were found in the sludge samples from the holding pond and from the landfill near the Hopewell Sewage Treatment plant. Fish and shellfish from the James River near Hopewell were found to contain 0.1 - 20 ppm kepone (20). The concentration of two PCBs in sludge from a number of municipal wastewater plants in Michigan ranged from less than 0.1 mg/l to 352 mg/l (21,22). As would be expected, the concentrations of the organics are considerably greater in sludges than in wastewater.

The wastewater and sludges at the wastewater treatment plant, Raisin River water and sediment, roadside soil and air in Adrian, Michigan were found in early 1979 to be widely contaminated with Curene 442 (MOCA, 4,4'-Methylene-bis(2-chloroaniline), a potential human carcinogen (23). Curene 442 is used as a curing agent for isocyanate-containing polymers and polyurethane elastomers. The source of contamination was traced to discharges received by the Adrian Wastewater Treatment Plant from Anderson Development Company over a period of several years. Curene 442 is not very soluble in water and therefore tends to accumulate in sludges and soils. The Anderson Development Company also has a highly contaminated storage lagoon. Soil samples taken in April 1979 at the Anderson Development Company plant site and in the adjacent neighborhood showed concentrations of up to 590 ppm of Curene 442. Anderson Development Company has discontinued production of Curene 442 in February 1979 by order of Michigan Department of Natural Resources. The amounts of Curene 442 (MOCA) found in the wastewater treatment plant effluents and sludges, Anderson Development Company lagoon water and sediment, Raisin River water and sediment, roadside soil and air in Adrian, Michigan are listed in Table 4 (23). As can be seen from Table 4, the Curene 442 (MOCA) contamination in Adrian, Michigan is widespread.

Although the list of compounds shown in Tables 1-3 is quite extensive, it is by no means exclusive, as to the total number or types of organic compounds present. At present the identification of organic compounds in wastewaters and sludges is limited by the volatility of the compounds and the available analytical techniques. Most organic compounds which come directly from industrial effluents or are metabolites or degradation products can not be readily detected or determined by the available analytical procedures. This is especially true for compounds with high molecular weights and with more hydrophilic compounds.

TABLE 4. CURENE 442[a] (MOCA)[b] LEVELS IN WASTEWATER, SLUDGE, RIVER WATER AND SEDIMENT, SOIL AND AIR IN ADRIAN, MICHIGAN (23)

Date Sampled	Type and location of sample	Curene 442[a] (MOCA)[b]	Source/Comments
	Wastewater (µg/l)		
2/7/79	Adrian WWTP[c]		Water Quality Division, MDNR[d]
	Influent	3.00	
	Effluent	4.10	
	Lagoon effluent	2800.00	
	Adrian sanitary sewer at ADC[e] lagoon outfall	1200.00	
	Adrian eastside drain water	2.00	
	Adrian eastside drain sediment	1200.00	
2/28/79	Adrian WWTP[c] runoff from sludge field	140.00	Environmental Services Division, MDNR[d]
3/12/79 to 3/13/79	Adrian eastside drain water	6.80	Environmental Services Division, MDNR[d]
	Adrian eastside drain sediment	11,000-95,000.00	
3/13/79	Process wastewater discharged by ADC[e] to Adrian WWTP[c]	230-440.00	Environmental Protection Bureau, MDNR[d]
3/13/79	Adrian WWTP[c] effluent	1.00	Analytical Laboratory Division of Chemical Technology, U.S. FDA, Washington, D.C.
	Adrian eastside drain water	1.00	
	ADC[e] lagoon water	250-350.00	
5/12/79	Adrian WWTP[c] influent	0.50	Environmental Protection Bureau, MDNR[d]
	Adrian WWTP[c] effluent	0.30	
	Sludge (mg/kg)		
2/7/79	ADC[e] lagoon sludge	2000.00	Water Quality Division, MDNR[d]
	Adrian WWTP[c]		
	Return sludge	0.006	
	Digested sludge	1.70	
3/13/79	ADC[e] lagoon sediment	16,000.00	U.S. FDA, Washington, D.C.
	Adrian WWTP[c] sludge	18.00	
5/12/79	Adrian WWTP[c] sludge from dry beds	86.00	Environmental Protection Bureau, MDNR[d]

(continued)

TABLE 4 (continued)

Date sampled	Type and location of sample	Curene 442[a] (MOCA)[b]	Source/Comments
	River Water and Sediment		
3/12/79 to 3/13/79	South branch Raisin River water	<0.10 µg/l	Environmental Services Division, MDNR[d]
	South branch Raisin River sediment	1.30-9.60 mg/kg	
	Groundwater (µg/l)		
2/7/79	ADC[e] well water	200.00	Water Quality Division, MDNR[d]
2/28/79	Adrian WWTP[c] dewatering well	<0.10	Environmental Services Division, MDNR[d]
3/13/79	ADC[e] well water	1.50	U.S. FDA, Washington, D.C.
6/27/79 to 6/28/79	Adrian WWTP[c] observation well	0.30	Water Quality Division, MDNR[d]
	Soil		
2/28/79	Adrian WWTP[c]-soil sample near well A	1600 µg/kg	Environmental Services Division, MDNR[d]
	Adrian WWTP[c]-soil sample near well B	6500 µg/kg	
4/5/79	Adrian public roads, surface soil	<0.05-590 ppm W/W	Air Quality Division, MDNR[d]
5/4/79	Adrian public roads surface soil		Environmental Enforcement Division, MDNR[d]
	4/10 mile from ADC[e]	13 ppm W/W	
	3/4 mile from ADC[e]	1.3 ppm W/W	
	over 1 mile from ADC[e]	2.1 ppm W/W	
5/8/79	Adrian residential sampling-vacuum cleaner dust from homes near ADC[e]	1.8-21 mg/kg	Environmental Enforcement Division, MDNR[d]
5/29/79	Garden soil from homes near ADC[e]		Michigan Department of Agriculture
	Soil surface	0.08-2.90 ppm	
	Soil 2-6" subsurface	0.02-0.86 ppm	
	Soil 6-10" subsurface	0.01-0.07 ppm	

(continued)

TABLE 4 (continued)

Date sampled	Type and location of sample	Curene 442[a] (MOCA)[b]	Source/Comments
	Air		
5/24/79 to 6/6/79	Air samples in Adrian surrounding ADC[e]	4.57 ng/m^3	Air Quality Division, MDNR[d]
	Adrian area dust surrounding ADC[e]	23 ppm	

a. Anderson Development Company's trade name for 4,4'-methylene-bis(2-chloroaniline).

b. Dupont Company's trade name for 4,4'-methylene-bis(2-chloroaniline)

c. Wastewater treatment plant.

d. Michigan Department of Natural Resources.

e. Anderson Development Company.

SECTION 5

FATE OF THE ORGANIC CHEMICALS ON LAND (4,24)

Several investigations have been conducted to determine the fate of disease-causing microorganisms, nitrogen, and phosphorus in the wastewater during the course of land application. Little is known at the present time about the fate of potentially toxic chemicals in the wastewater and their possible pathways in soils. Hazardous substances in wastewater that are not removed during the treatment process may pose a present or potential long-term danger to human health or to other living organisms because they are often nonbiodegradable, bio-accumulate,or persistent in the environment.

The concentrations of organic chemicals are usually low (μg/l) in treated wastewater effluents and sludges. Repeated application on land may result in accumulation of organic chemicals in soil. The ionizability, water solubility,and structure-function relationships (25) of the organic chemicals determine to a great extent their ultimate fate and behavior in soil and the environment.

The behavior and decomposition pathway of many pesticide residues which constitute a significant fraction of the persistent organics in soils has been studied for many years (26). Organic chemicals in wastewater and sludge applied to land could be expected to be influenced by the same processes that affect the fate and behavior of organic pesticides. Some of the processes that can cause the breakdown of pesticides are photodecomposition, chemical and microbiological decomposition,and detoxification by crop plants or weeds. Several factors such as pH, surface activity and solubility affect the degradation rate. Microbial degradation is influenced by the microbial population and by factors affecting microbial activity. Simple organic compounds such as aliphatic and phenolic acids, amino acids and sugars are readily decomposed by soil microorganisms. Highly chlorinated or halogenated compounds, and compounds with branched chains and higher molecular weight, are more resistant to biodegradation and require longer periods of time to decompose in soils. Transfer processes move and dilute the pesticides keeping their chemical structures intact.. These include:

(1) volatilization,

(2) movement into and out of plants by adsorption and exudation,

(3) retention by crop plants and weeds in small amounts,

(4) runoff into streams and lakes,

(5) movement downward into the soil in percolating water and upward from lower depths by capillary flow, and

(6) adsorption and inactivation by soil constituents (24).

The adsorption phenomena of soils could increase the organic chemical concentration at the soil surface and, therefore, make them more susceptible to microbial decomposition. The adsorption generally decreased in the order: organic matter > vermiculite > montmorillonite > illite > chlorite > kaolinite (4). Adsorption of organic pesticides by soil also characteristically increases as the concentration of functional groups such as primary, secondary and tertiary amines, amides, carboxyl, and phenolic groups increase. The presence of organic substances usually increases the adsorption affinity. The pesticides can also be effectively bonded with iron and aluminum oxides at proper soil pH ranges (4). Both laboratory and field studies indicate that many pesticide residues adsorb to surface soils with only a few migrating to depths of 30-60 cm in soil (27). Besides adsorption of organic pesticides and other chemicals by soil, chemical reaction with functional groups on humates can also occur. The immobilized organic substances in soils are subsequently subject to chemical or photochemical decomposition, volatilization and microbial decomposition. With existing data it is difficult to project the long-term effectiveness and the consistency of soil mantle to immobilize and detoxify hazardous substances in wastewater. Therefore, adequate studies should be done to determine the actual fate of the chemical contaminants present in wastewaters and sludges.

The study conducted at Muskegon, Michigan, focused on the behavior of many of these compounds in land disposal (11). The study showed that the concentrations of many of the chemicals present in raw wastewater following spray irrigation were reduced below the detection limits in the effluent by treatment consisting of an aerated lagoon and filtration through several feet of sand. From Table 2, it appears that the majority of the removal took place in the storage lagoon and in the spray irrigation-percolation system.

SECTION 6

CONTROL OF THE ORGANIC CHEMICALS

Control of organic chemicals can be in the form of discharge standards for organics in wastewater effluents. EPA has proposed standards for drinking water (Table 5) (28) and for some toxic effluents (Table 6) (29,30). Water quality criteria proposed by EPA for some toxic organic chemicals that would form the basis for state water quality standards and EPA toxic effluent standards are listed in Table 7 (31-33). These criteria are an indication of the maximum concentration of a pollutant in water which, when not exceeded, will insure protection of specified water use. Dacre proposes SPLVs (soil pollutant limit values) to control the hazard loads of toxic chemicals in soils (2). These values may be compared with Threshold Limit Values (TLVs), which refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. The control measures should take into account acceptable daily intake (ADI) values. ADI values estimated by World Health Organization for some pesticide chemicals to which man may be exposed are shown in Table 8 (34,35). The ADI values and SPLVs could possibly be adapted for municipal wastewater effluents and sludges. Table 9 lists SPLVs for some of the insecticides identified in sludges (2).

TABLE 5. NATIONAL INTERIM PRIMARY DRINKING WATER STANDARDS (28)
MAXIMUM CONTAMINANT LEVELS (mg/l)

Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
2,4-D	0.1
2,4,5-TP	0.01

TABLE 6. TOXIC POLLUTANT EFFLUENT STANDARDS (29,30)
(µg/l)

Aldrin/Dieldrin	0.003
DDT (DDD, DDE)	0.001
Endrin	0.004
Toxaphene	0.005
PCBs	0.001
Benzidine	0.1

TABLE 7. AMBIENT WATER QUALITY CRITERIA PROPOSED BY EPA FOR SOME TOXIC ORGANIC POLLUTANTS (31-33)

Organic Pollutant	Freshwater aquatic life 24 hr. average (ceiling) µg/l	Saltwater aquatic life 24 hr. average (ceiling) µg/l
Acenaphthene	110 (240)	7.5 (17)
Acrolein	1.2 (2.7)	0.88 (2.0)
Acrylonitrile	130 (300)	130 (290)
Aldrin/Dieldrin	0.0019 (1.2)	0.0069 (0.16)
Benzene	3100 (7000)	920 (2100)
4-Bromophenyl phenyl ether	6.2 (14)	--
Carbontetrachloride	620 (1400)	2000 (4600)
Chlordane	0.024 (0.36)	0.0091 (0.18)
Chlorinated benzenes		
Chlorobenzene	1500 (3500)	120 (280)
1,2-Dichlorobenzene	44 (99)	15 (34)
1,3-Dichlorobenzene	310 (700)	22 (49)
1,4-Dichlorobenzene	190 (440)	15 (34)
1,2,4-Trichlorobenzene	210 (470)	3.4 (7.8)
1,2,3,5-Tetrachlorobenzene	170 (390)	2.6 (5.9)
1,2,4,5-Tetrachlorobenzene	97 (220)	9.6 (26)
Pentachlorobenzene	16 (36)	1.3 (2.9)
Chlorinated ethanes		
1,2-Dichloroethane	3900 (8800)	880 (2000)
1,1,1-Trichloroethane	5300 (12,000)	240 (540)
1,1,2-Trichloroethane	310 (710)	--
1,1,1,2-Tetrachloroethane	420 (960)	--
1,1,2,2-Tetrachloroethane	170 (380)	70 (160)
Pentachloroethane	440 (1000)	38 (87)
Hexachloroethane	62 (140)	7.0 (16)
Chlorinated phenols		
2-Chlorophenol	60 (180)	--
4-Chlorophenol	45 (180)	--
2,4,6-Trichlorophenol	52 (150)	--
Pentachlorophenol	6.2 (14)	3.7 (8.5)
Chloroform	500 (1200)	620 (1400)

(continued)

TABLE 7 (continued)

Organic pollutant	Freshwater aquatic life 24 hr. average (ceiling) µg/l	Saltwater aquatic life 24 hr. average (ceiling) µg/l
1-Chloronaphthalene	29 (67)	2.8 (6.4)
Cyanide	1.4 (3.8)	--
DDT and metabolites	0.00023 (0.41)	0.0067 (0.021)
Dichloroethylenes		
1,1-Dichloroethylene	530 (1200)	1700 (3900)
1,2-Dichloroethylene	620 (1400)	--
2,4-Dichlorophenol	0.4 (110)	--
Dichloropropanes		
1,1-Dichloropropane	410 (930)	--
1,2-Dichloropropane	920 (2100)	400 (910)
1,3-Dichloropropane	4800 (11,000)	79 (180)
1,3-Dichloropropene	18 (250)	5.5 (14)
2,4-Dimethylphenol	38 (86)	--
Dinitrotoluenes		
2,3-Dinitrotoluene	12 (27)	4.4 (10)
2,4-Dinitrotoluene	620 (1400)	--
1,2-Diphenylhydrazine	17 (38)	--
Endosulfan	0.042 (0.49)	--
Endrin	0.002 (0.10)	0.0047 (0.031)
Fluoranthrene	250 (560)	0.3 (0.69)
Halomethanes		
CH_3Cl	7000 (16,000)	3700 (8400)
CH_3Br	140 (320)	170 (380)
CH_2Cl_2	4000 (9000)	1900 (4400)
$CHBr_3$	840 (1900)	180 (420)
Heptachlor	0.0015 (0.45)	0.0036 (0.05)
Hexachlorocyclopentadiene	0.39 (7.0)	--

(continued)

TABLE 7 (continued)

Organic pollutant	Freshwater aquatic life 24 hr. average (ceiling) µg/l	Saltwater aquatic life 24 hr. average (ceiling) µg/l
Isophorone	2100 (4700)	97 (220)
Lindane	0.21 (2.9)	--
Nitrobenzene	480 (1100)	53 (120)
Nitrophenols		
2-Nitrophenol	2700 (6200)	--
4-Nitrophenol	240 (550)	53 (120)
2,4-Dintrophenol	79 (180)	37 (84)
2,4-Dinitro-6-methylphenol	57 (130)	--
2,4,6-Trinitrophenol	1500 (3400)	150 (340)
PCBs	0.0015 (6.2)	0.024 (0.20)
Phenol	600 (3400)	--
Tetrachloroethylene	310 (700)	79 (180)
Toluene	2300 (5200)	100 (230)
Toxaphene	0.007 (0.47)	0.019 (0.12)
Trichloroethylene	1500 (3400)	--

TABLE 8. MAXIMUM ACCEPTABLE DAILY INTAKES FOR SOME PESTICIDES (34,35)
(mg/kg body wt/day)

Aldrin	0.0001
Dieldrin	0.0001
Endrin	0.0002
Chlordane	0.001
DDT	0.005
Heptachlor	0.0005
Lindane	0.0125
2,4-D	0.3

TABLE 9. SOIL POLLUTANT LIMIT VALUES (PROVISIONAL) (2)
(mg/kg dry soil)

Aldrin	0.0024
Dieldrin	0.0024
Endrin	0.0048
Chlordane	0.024
DDT (DDD, DDE)	0.0000002

SECTION 7

EFFECT OF THE ORGANIC CHEMICALS

EFFECT ON WASTEWATER TREATMENT PLANT WORKERS

(a) The workers at the wastewater treatment plant in Adrian, Michigan were exposed to Curene 442 (MOCA, Methylene-bis(2-chloroaniline)) in wastewater and sludges over a period of several years (23). The source of Curene 442 was discharges from Anderson Development Company in Adrian, Michigan. Based on tissue culture carcinogenicity tests and animal test studies in mice, rats, and female beagle dogs, National Institute of Occupational Safety and Health (NIOSH) considered Curene 442 (MOCA) a potential human carcinogen (36). Curene 442 has a very low solubility in water. It also has very low vapor pressure. Therefore Curene 442 tends to accumulate in sludges and soils. It is reported to be readily absorbed through skin. Workers handling sludge would, therefore, be at a potential risk from exposure to Curene 442. The Michigan Department of Public Health analyzed urine specimens from Adrian wastewater treatment plant operators for Curene 442 in May 1979 but found no evidence of its presence. However, Curene 442 was detected in the blood and urine specimens of Anderson Development Company's workers. There are no conclusive epidemiological studies at present on which an evaluation of the carcinogenic risk to Adrian wastewater treatment plant workers can be based.

(b) Several acute toxic effects have been reported by the treatment plant workers at the Morris Forman Plant in Louisville, Kentucky, and at the North Treatment Plant in Memphis, Tennessee, when exposed to toxic pesticide chemical wastes. In Louisville, Kentucky, the exposure was a result of unauthorized use in March 1977 of a combined sewer for the dumping of a highly toxic pesticide waste material containing hexachlorocyclopentadiene (Hexa) and octachlorocyclopentene (Octa) (37-39). Workers involved in the steam cleaning of the mechanical screen complained of eye irritation, burning skin above the arms and face, sore throat and symptoms similar to bronchitis. Airborne concentrations of Hexa at the time of exposure were unknown but four days after the episode, the air concentrations in the primary treatment areas (screen and grit chambers) ranged from 270-970 ppb. By comparison, the recommended TLV for occupational exposure to Hexa is 10 ppb (40). The incident forced the treatment plant to shut down the operation voluntarily from March 29, 1977 to June 5, 1977 resulting in the discharge of untreated sewage containing toxic chemical waste directly into the Ohio River.

In Memphis, Tennessee, the situation is not a one time dumping of toxic chemical waste but an apparent continuous entry of the wastes into the treatment plant from a pesticide formulator since it was first opened in

1977. Ironically, the waste material that was dumped into the Louisville sewer system is believed to have originated from the same company. The exposure at both plants is to the same pesticide material, except that in Memphis, Tennessee, there are many other chemicals present besides Hexa. Also in Memphis, Tennessee, the exposure is one of an almost continuous nature to variable but generally low levels of these chemicals whose long-term toxic effects are not known. Acute effects were reported when the discharge was heavy (41,42).

(c) Eight workers at the wastewater treatment plant in Bloomington, Indiana, were exposed to PCBs discharged by the Westinghouse Corporation. Analyses of tissue samples showed that PCBs were present in all eight workers. Two of these workers, who had previously worked at the Westinghouse plant, had PCBs levels of 10.4 and 10.1 ppm (lipid basis). The other six had an average level of 6 ppm. The levels found in these workers are higher than levels found in a national monitoring survey in which only 5% out of a total 637 tissue samples tested had levels higher than 2 ppm. Even though the acute toxicity of PCBs is low, the long-term effects of exposure to PCBs are not known and experiments with laboratory animals have associated PCBs with stillbirths, miscarriages and various metabolic disorders. The toxic effects of ingestion of PCBs on humans had been demonstrated in a 1968 episode in Japan where a batch of rice oil was accidentally contaminated by PCBs (discussed on page 41) (15,43).

There is no information available at present on the health effects of organics on workers involved in the transportation and/or land spreading of wastewater or sludge.

Information from the study of health effects of pesticides in agricultural use may be useful in this respect. An evaluation of agricultural exposure was not included in this review.

EFFECT ON OTHER POPULATIONS

(a) No information is available at present on the effects of organics in wastewaters and sludge on populations living near wastewater treatment plants.

(b) No information is available at present on the health effects of organics on populations living near facilities where land application is practiced. At present there are only a few epidemiological studies being conducted on the potential health risks associated with the land application of wastewater and/or sludge to agricultural lands, some of which follow:

(i) A retrospective and a prospective study in Israel on populations engaged in land application of wastewater (44);

(ii) A prospective study by Ohio Farm Bureau on potential health effects to farmers involved with land application of sludge (45);

(iii) A short-term prospective study of the workers at a wastewater spray irrigation facility in Muskegon, Michigan (46).

Of these, only the study at Muskegon, Michigan, is taking into consideration the potential health effects of organic chemicals.

(c) Two examples of populations affected by leachates from industrial waste landfills are:

(i) In Toone, Tennessee, residential drinking water supplies were contaminated by chlorinated pesticide waste chemicals leaching from an old landfill that was used by Velsicol Chemical Corporation for dumping chlorinated pesticide residues from its Memphis, Tennessee, operation (47,48). Some of the symptoms that have been noticed since the fall of 1977 which the residents associate with the contamination of their water supplies are - skin and eye irritation, weakness in joints and persistent cough (49).

(ii) In Love Canal, Niagara Falls, New York, where houses and an elementary school were built on an old Hooker Chemical Company landfill site, the chemicals leached into the groundwater and were brought back to the surface by rising water tables causing groundwater and air pollution. The rate of miscarriages in this community are reported to be one to five times higher than expected and an excess of birth defects was also noticed (50). However, data to support their conclusions have not yet been published. Many of the residents of this community were evacuated from their homes.

Even though these landfills are not in use now, they are discharging long-abandoned toxic waste chemicals into air and water. Ironically, Hooker Chemical waste and Velsicol Chemical waste in the past were very similar since some of their products were similar.

WATER POLLUTION

(a) Surface Water Pollution: Lateral dispersion by runoff can cause surface water pollution by organic chemicals with the possibility of contaminating drinking water supplies. However, there are no published accounts of situations where surface drinking water supplies have been contaminated by organic chemicals in wastewaters and sludge used for land application. Surface water pollution by organic chemicals can also result from chemical waste discharges from industries. Some examples follow:

(i) Raisin River Pollution by Curene 442 (MOCA) in Adrian, Michigan (1979) (23): The wastewater and sludges at the wastewater treatment plant in Adrian, Michigan, were contaminated with Curene 442 (MOCA) which was discharged by Anderson Development Company. The wastewater treatment plant discharges effluents into the Raisin River. The water and sediment of the Raisin River were found to be contaminated with Curene 442 (MOCA) (Table 4). The Michigan Department of Public Health has expressed concern for the communities of Blissfield, Deerfield, and Dundee who use the Raisin River as a drinking water supply.

(ii) Hudson River Pollution by PCBs (1974) (16): Hudson River has been contaminated by PCBs discharged from two General Electric plants in Fort Edward - Hudson Falls area about 40 miles north of Albany. The General Electric plants manufacture electrical capacitors in which PCBs are used as insulating fluids. General Electric was one of the largest users of PCBs manufactured by the Monsanto Company, and about 30 pounds of PCBs were discharged into the Hudson River every day. The discharges appear to have declined to less than 10 pounds per day in recent years. PCBs are chlorinated hydrocarbons similar to DDT. They are insoluble in water, highly resistant to heat, and not readily decomposed, thus making them very persistent environmental contaminants. They accumulate in river-bottom sediments because of their insolubility in water. Analyses of water and sediment samples in Hudson River during the years 1973 and 1974 by U.S. Geological Survey showed 0.3 to 3.0 ppb of PCBs in water and up to 18,000 ppb of PCBs in the sediment. A later survey by EPA, Region II showed 2.2 - 3.1 ppb of PCBs in water and 540 - 2980 ppm of PCBs in the sediment near the General Electric plant discharges, with 660 ppm being detected several miles downstream (17). Fish were found to be contaminated not only near the General Electric plants but also several hundred miles south of the plants indicating long-range transport of PCBs discharged by industrial activities. The toxic effects of ingestion of PCBs on humans had been demonstrated in a 1968 episode in Japan where a batch of rice oil was accidentally contaminated by PCBs (discussed on page 41).

(iii) Clear Creek Pollution by PCBs in Bloomington, Indiana (1976) (15): Waste discharges by the Westinghouse Electric Corporation in Bloomington, Indiana, into the city sewer system and storm water runoff from outdoor facilities at the Westinghouse plant have contaminated the Clear Creek and other streams in the area with PCBs. The Westinghouse plant manufactures electrical capacitors in which PCBs are used as insulating fluids. The company discharges about one to eight pounds of PCBs per day into the city sewer system. The wastewater effluents of the Bloomington, Indiana, sewage treatment plant which were discharged into Clear Creek contained 19-47 ppb of PCBs. The sediment of Clear Creek, was found to contain 18 ppm of PCBs. This creek flows into Salt Creek which flows into the East Fork of the White River, a tributary of the Ohio River. The fish in Clear Creek, Salt Creek, and the West Fork of White River were all found to be contaminated with PCBs thus making them unsuitable for human consumption (15).

(iv) James River Pollution by Kepone in Virginia (1975) (51,52): Fish and sediment in James River, near Hopewell, Virginia, were found to be contaminated with kepone, a chlorinated pesticide used mainly against potato beetles in Europe. The river was closed to commercial fishing from Hopewell, Virginia, to a point 84 miles

downstream where it enters Chesapeake Bay. Kepone was manufactured by Allied Chemical from 1968 to 1973 intermittently at the Hopewell, Virginia, plant. A new company called Life Science Products, formed by two former Allied Chemical employees, resumed production of kepone under a subcontract from Allied Chemical. During 1968 to 1973, Allied Chemical discharged its waste from kepone manufacturing plant into James River without a permit. The Life Sciences Products discharged its waste into Hopewell's sewerage system, which eventually discharged into James River. Life Science's discharge of kepone waste into the city sewerage system resulted in closing down the sewage treatment plant because kepone inhibited the normal bacterial action required for sewage treatment, and the untreated sewage wastes were discharged into the James River. Kepone has been found to be widely distributed throughout the Hopewell, Virginia, area and the James River was closed to fishing in December 1975. Even though there is no known evidence of short-term health effects in the general population and the long-term effects of exposure to kepone are not known, the toxicity of kepone is well documented in workers of Life Science Products. They had symptoms of severe headaches, tremors, memory loss, liver damage, slurred speech, and involuntary rolling of eyes. Many of them had become sterile. The half-life of kepone in human body is 165 days.

(v) Ohio River contamination by CCl_4 (1977) (53): For several years, FMC Corporation in Huntington, West Virginia, had been discharging 2000 to 4000 pounds of CCl_4 every day into the Kanawha River which flows into the Ohio River. The discharges were in violation of a court-ordered consent decree by EPA designed to end excessive discharges of CCl_4 into the Kanawha River. The largest spill to date in February 1977 of 70 tons, raised the levels of CCl_4 in Cincinnati drinking water to 80 ppb. The effects of long-term exposure to low levels of CCl_4 are not known but studies have shown CCl_4 to be carcinogenic in laboratory animals (7).

(vi) The illicit dumping of toxic chemical waste into the Louisville, Kentucky, sewerage system forced the treatment plant to shut down operation from March 29, 1977 to June 5, 1977 resulting in discharging of untreated sewage containing toxic chemical waste directly into the Ohio River (37-39).

(b) Groundwater Pollution: Groundwater contamination can occur from collection, treatment, and disposal of municipal wastewater by the following routes:

- leakage from collecting sewers
- leakage from treatment plant lagoons
- land disposal of treatment plant effluents and disposal to surface water bodies that recharge aquifers
- land disposal of sludges that are subject to leaching.

Although the volume of wastewater entering the groundwater system from these various sources may be substantial, there have been few documented cases of hazardous levels of constituents of sewage affecting well water supplies, largely because the subject has not been studied in detail. A large proportion of the sewage treatment plant effluents discharged to land do not meet secondary treatment standards (54).

The impact on groundwater of diffuse land spreading of municipal sludge is practically unknown because fewer than 1% of the present municipal sludge land spreading disposal facilities are monitored for effect on water quality. (59). Groundwater pollution by organic chemicals can also occur from leaching of toxic chemicals from industrial waste landfills, municipal solid waste disposal sites, or agricultural use of pesticides.

(i) Industrial waste landfills are a source of serious groundwater contamination because of their large number and potential for leaking hazardous substances that are relatively mobile into the groundwater environment. The contaminants cover the full range of organic and inorganic chemicals normally present in industrial wastewaters. Those documented as having degraded groundwater quality include phenols, acids, heavy metals, chlorinated hydrocarbons and cyanide (54). Hazardous chemicals are often present in the leachate from industrial waste landfills (e.g., CN, Cd, Cr, chlorinated hydrocarbons, and PCBs). The particular make-up of the leachate is dependent upon the industry using the landfill or dump (54). This source of contamination is one of the most frequently reported in spite of the almost complete lack of groundwater monitoring. Toone, Tennessee, described in an earlier section, is an example where groundwater pollution has occurred from leachates from a toxic waste landfill.

Dover Township, New Jersey, is another example where groundwater pollution had occurred from industrial waste landfill. Residents of this community noticed taste and odor problems with their drinking water in 1974. Tests showed petrochemicals in the water in the ppm range, and as a result 148 wells were permanently condemned. Three years earlier, several thousand drums of toxic, flammable, explosive, and oxidizing wastes had been dumped on nearby property. Damages for capping wells, removing drums, drilling deeper wells, emergency water, water analysis, extension of public water and installing observation wells came to over $400,000 (55).

(ii) Land disposal sites for municipal solid wastes can be sources of groundwater contamination because of the generation of the leachates caused by water percolating through the bodies of refuse and waste materials. Leachate can be a highly mineralized fluid containing such constitutents as chloride, Fe, Pb, Cu, Na, nitrate, and a variety of organic chemicals (54).

Many problems with leachates in groundwaters have been at least partially documented. A recent report for the northeastern

U.S., for example, documented 60 cases in which well supplies were made unsuitable for domestic consumption (56).

(iii) A study of the extent of pesticide levels in rural drinking waters of two counties in South Carolina was carried out to determine the role of agricultural practices and other possible sources (57). One of the counties was known to have received a higher amount of the pesticides over a period of several years than the other from the information obtained from the County Extension Service. The study showed that the pesticide levels found in the drinking waters of the county that received a higher amount of the pesticides were lower than in the county that received a lower amount of the pesticides. Such factors as well location, depth or type of construction were found to have little or no direct bearing on the residue levels. The authors believed that local environmental conditions other than agricultural pesticidal use may have some bearing. The pesticidal residues observed were the chlorinated hydrocarbons with DDT, lindane, dieldrin, and mirex being most common. Although the study concluded that the pesticidal residues found in the drinking waters of the two counties were well below the accepted limits, a comparison with the national interim primary drinking water standards (28) revealed that some are above the recommended levels and therefore caution should be exercised in using the affected water supplies.

EFFECT ON THE FOOD CHAIN

Only a limited amount of information is available on the effects of the food chain of the organic chemicals present in wastewater and sludge used in land application. Wastewater application methods are important in assessing potential food contamination. Methods of field application of wastewater and sludge can be one of a variety of surface or subsurface application methods (58). The choice of the methods depends on the individual land application facility, geographic location, and climate.

Primary attention should probably be given to organic compounds that are known to be potentially toxic and carcinogenic such as organochlorine pesticides, polycyclic aromatic hydrocarbons, PCBs, etc. (Tables 5-7). The organochlorine compounds are of particular concern because most of them have been found to be known or suspected carcinogens in animal models, are highly resistant to degradation, and are lipid soluble. This accounts for their accumulation and translocation to animals and humans via food chain (Figure 1, Insecticide Cycle) (2,59). The toxicological properties of some of the pesticides - LD_{50}, fatal dose and the levels at which chronic poisoning and acute poisoning, etc. occur are summarized in Table 10 (60-62).

The ambient water quality criteria proposed by EPA for the protection of human health from the adverse health effects caused by ingestion of toxic organic chemicals in water are shown in Table 11 (31-33). EPA has recommended human health criteria in water of zero for carcinogens, but since this is not feasible at present, EPA provided criteria for achieving various levels of protection on an interim basis as shown in Table 12 (31-33). Tolerance

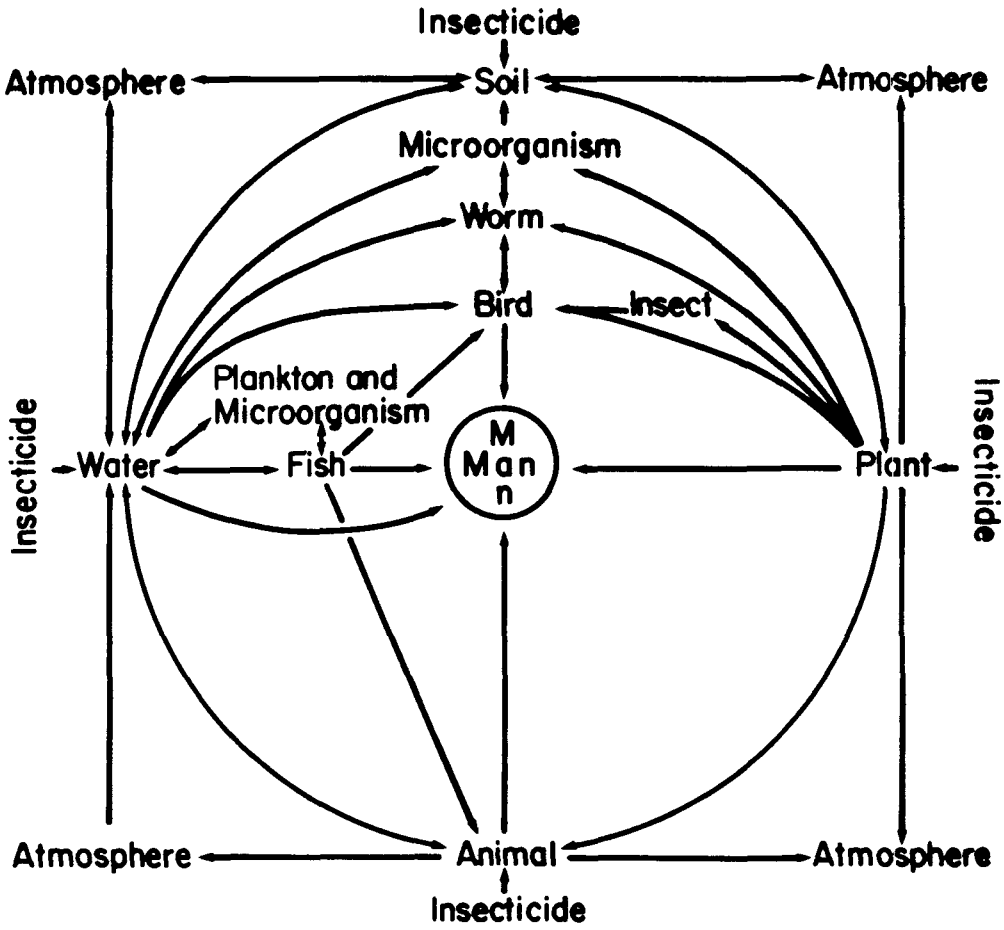

Figure 1. Insecticide cycle (2,59)[a]

a) Reprinted from C.M. Tu and J.R.W. Miles, Residue Reviews, 64, 17-65 (1976), with permission of F.A. Gunther, Ed., Springer-Verlag, New York, N.Y.

TABLE 10. PESTICIDES IN THE ENVIRONMENT AND THEIR TOXICITY (60-62)

Pesticide	LD^a_{50}(oral) g/kg	Fatal doses (g/kg)	Chronic poisoning	Acute Poisoning
DDT	Rat 0.285 Rabbit 0.325	0.4	Not substantiated. Having 648 ppm in their body remained well.	Severe vomiting within 30 min to 1 hr of 5 g. Weakness and numbness of the extremities. Apprehension and excitement are marked.
Dieldrin	Rat 0.06 Dog 0.068 Rabbit 0.045	0.07	Not been established in man. Impair liver function in animals, occasional epileptiform convulsions.	Hyperexcitability, tremors, ataxia, convulsions.
Lindane (benzene hexachloride)	Rat 0.135 Dog 0.12 Rabbit 0.13	0.6	In animals, liver necrosis.	Vomiting and diarrhea, convulsions, circulatory failure.
Malathion	Rat 2.5	0.86	In animals, colinesterase levels of red blood cells and plasma are reduced markedly.	Headache, tremors, nausea, abdominal cramps, diarrhea, coma, heat block.
Parthion	Rat 0.004	0.0014	Not established in man.	Similar to those of malathion, but more severe and fatal.
2,4-D	Mouse 0.375	0.7	Weakness, fall of blood pressure, muscle damage.	Burning pain, painful and tender muscle, fever, paralysis, irreversible fall of blood pressure.
2,4,5-T	Rat 0.3 Dog 0.1	0.6	Similar to 2,4-D.	Similar to 2,4-D.

a. LD_{50}: Median lethal dose of a substance that will kill 50% of the experimental subjects.

TABLE 11. HUMAN HEALTH CRITERIA PROPOSED BY EPA FOR SOME TOXIC ORGANIC CHEMICALS IN AMBIENT WATER (31-33)

Organic compound	Human health effects criterion (µg/l)
Acenaphthene	20.00
Acrolein	6.50
Bis(2-Chloroisopropyl) ether	175.80
Chlorinated benzenes	
Chlorobenzene	20.00
Trichlorobenzene	13.00
Tetrachlorobenzene	17.00
Pentachlorobenzene	0.50
Chlorinated naphthalenes	
Trichloronaphthalene	3.90
Tetrachloronaphthalene	1.50
Pentachloronaphthalene	0.39
Hexachloronaphthalene	0.15
Octachloronaphthalene	0.08
Chlorinated phenols	
2-Chlorophenol	0.30
3-Chlorophenol	50.00
4-Chlorophenol	30.00
2,5-Dichlorophenol	3.00
2,4,5-Trichlorophenol	10.00
2,4,6-Trichlorophenol	100.00
2,3,4,6-Tetrachlorophenol	263.00
Pentachlorophenol	140.00
Cyanide	200.00
Dichlorobenzenes (all isomers combined)	230.00
2,4-Dichlorophenol	0.50
Dichloropropanes	200.00
Dichloropropenes	0.63
Endosulfan	100.00
Endrin	1.00
Ethylbenzene	110.00

(continued)

TABLE 11 (continued)

Organic compound	Human health effects criterion (µg/l)
Fluoranthrene	200.00
Halomethanes	
CH_3Cl	2.00
CH_3Br	2.00
CH_2Cl_2	2.00
$CHBr_3$	2.00
$CHCl_2Br$	2.00
CCl_2F_2	3000.00
CF_3Cl	32,000.00
Isophorone	460.00
Naphthalene	143.00
Nitrobenzene	30.00
Nitrophenols	
Dinitrophenols	68.60
Trinitrophenols	10.00
Dinitrocresols	12.30
Phenol	340.00
Phthalate esters	
Dimethyl ester	160,000.00
Diethyl ester	60,000.00
Dibutyl ester	5000.00
Di-2-ethyl hexyl ester	10,000.00
Toluene	17,400.00
1,1,1-Trichloroethane	15,700.00

TABLE 12. INTERIM HUMAN HEALTH EFFECTS CRITERIA PROPOSED BY EPA FOR SOME CARCINOGENIC ORGANIC CHEMICALS IN AMBIENT WATER (31-33)

Organic carcinogen	Levels that would permit one case of cancer in specified population size exposed people (μg/l) 1/10 Million	1/1 Million	1/100,000
Acrylonitrile	0.0008	0.008	0.08
Aldrin	0.46×10^{-6}	0.46×10^{-5}	0.46×10^{-4}
Benzene	0.15	1.5	15
Benzidine	1.67×10^{-5}	1.67×10^{-4}	1.67×10^{-3}
Carbontetrachloride	0.026	0.26	2.6
Chlordane	0.012	0.12	1.2
Chloroalkyl ethers			
Bis(2-chloroisopropyl) ether	0.115	1.15	11.5
Bis(2-chloroethyl) ether	0.0042	0.042	0.42
Bis(chloromethyl) ether	0.2×10^{-6}	0.2×10^{-5}	0.2×10^{-4}
Chlorinated ethanes			
1,2-Dichloroethane	0.07	0.7	7.0
1,1,2-Trichloroethane	0.027	0.27	2.7
1,1,2,2-Tetrachloroethane	0.018	0.18	1.8
Hexachloroethane	0.059	0.59	5.9
Chloroform	0.021	0.21	2.1
DDT	0.98×10^{-5}	0.98×10^{-4}	0.98×10^{-3}
3,3'-Dichlorobenzidine (DCB)	0.001	0.01	0.1
1,1-Dichloroethylene	0.013	0.13	1.3
Dieldrin	0.44×10^{-6}	0.44×10^{-5}	0.44×10^{-4}
2,4-Dinitrotoluene	0.0074	0.074	0.74
1,2-Diphenylhydrazine	0.004	0.04	0.4
Heptachlor	0.23×10^{-5}	0.23×10^{-4}	0.23×10^{-3}
Hexachlorobenzene	1.25×10^{-5}	1.25×10^{-4}	1.25×10^{-3}
Hexachlorobutadiene	0.0077	0.077	0.77

(continued)

TABLE 12 (continued)

Organic carcinogen	Levels that would permit one case of cancer in specified population size exposed people (μg/l) 1/10 Million	1/1 Million	1/100,000
Hexachlorocyclohexane (HCH)			
α-HCH	1.6×10^{-4}	1.6×10^{-3}	0.016
β-HCH	2.8×10^{-4}	2.8×10^{-3}	0.028
γ-HCH	5.4×10^{-4}	5.4×10^{-3}	0.054
ρ-HCH	2.1×10^{-4}	2.1×10^{-3}	0.021
Nitrosamines			
N-Nitrosodimethylamine	2.6×10^{-4}	2.6×10^{-3}	0.026
N-Nitrosodiethylamine	0.92×10^{-4}	0.92×10^{-3}	0.0092
N-Nitrosodi-n-butylamine	1.3×10^{-4}	1.3×10^{-3}	0.013
N-Nitrosopyrolidine	0.0011	0.011	0.11
PCBs	2.0×10^{-6}	2.0×10^{-5}	2.0×10^{-4}
Polynuclear aromatic hydrocarbons			
Benz-a-pyrene (BaP)	0.97×10^{-4}	0.97×10^{-3}	0.0097
Dibenzanthracene (DBA)	0.43×10^{-4}	0.43×10^{-3}	0.0043
TCDD	0.455×10^{-8}	0.455×10^{-7}	0.455×10^{-6}
Tetrachloroethylene	0.02	0.2	2.0
Trichloroethylene	0.21	2.1	21
Vinyl chloride	5.17	51.7	517

limitations set by FDA for various pesticides and toxic organic chemicals in food products should be used for selective monitoring of vegetation grown on sludge-treated lands. Tolerance limitations set by FDA for PCBs in a variety of food products in 1973 and subsequently modified in 1979, are shown in Table 13 (63,64).

(a) Physical Contamination (5): Chaney and Lloyd (65) have shown that sewage sludges are effectively retained on the top of the vegetation when applied by spraying, and that they are not well removed by rain. Because of the more dilute nature (and lower viscosity) of wastewater and effluents, lower contamination levels on vegetation would be expected. However, evaporation and repeated application may provide sufficient buildup of contaminants to be a cause for concern. Contaminants physically retained on crops may be ingested by animals,or possibly directly by humans if improper practices are followed (66).

(b) Uptake by Plants: The extent to which organic chemicals in wastewaters and sludge, at the levels indicated in an earlier section, will be taken up by plants and may be toxic to human beings through food crops is not well understood (5,67).

The Michigan Department of Agriculture has analyzed fresh produce grown in household gardens close to Anderson Development Company in Adrian, Michigan (23). As mentioned in an earlier section, Curene 442 (MOCA), a potential human carcinogen, was found in discharges from the Anderson Development Company and in samples of garden soils in the residential area surrounding the Anderson Development Company (Table 4). It is believed that these household gardens did not receive municipal sludge from the Adrian wastewater treatment plant as a fertilizer, even though the wastewater treatment plant sludge was given away to home gardeners up until 1977. In a press release dated July 13, 1979, the Michigan Department of Agriculture stated that the results of analysis of limited samples tested in their laboratory showed no evidence of Curene 442 (MOCA) residues in thoroughly washed samples of onion tops and bulbs, zucchini and radishes.

The uptake of pesticides and PCBs from soils into plants has been studied to a limited extent. Plants do take up many pesticides through roots and translocate them within the plant (68). Some pesticides are taken up but others are not or are taken up at low levels (69). The pesticides heptachlor, dieldrin, and chlordane are taken up by soybean plants from soil, translocated to the seed and stored at low levels in the oil (70). PCBs on the other hand are not carried to the top of the soybean plants if direct vapor transmission is prevented by a barrier over the soil (71). Uptake of PCBs by root crops, however, has been demonstrated under field conditions. It was shown that carrot peel contained 97% of the root residue and very little was found in the foliage (72). Lawrence and Tosine (73) reported that the PCB concentration in the leaves of corn and grass grown on sludge-treated land was comparable to that in the sludge, whereas the Center for Disease Control (CDC) found negligible amounts of PCBs in vegetation grown in land treated with sludge containing PCB levels as high as 300 ppm in Bloomington, Indiana (15,74). For example, CDC found that beets grown in sludge-amended soil containing 4 ppm PCBs were found to have 0.6 ppm PCBs (1/7th of that in the soil), grass from a

TABLE 13. FDA TOLERANCES FOR PCBs IN FOOD AND FOOD PACKAGING (PPM) (63,64)

Milk[a]	1.5
Dairy products[a]	1.5
Poultry[a]	3.0
Fish and shellfish[b]	2.0
Eggs	0.3
Infant and junior food	0.2
Complete and finished animal feed	0.2
Animal feed components	2.0
Paper food-packaging material	10.0

a. On fat basis

b. Edible portion

field containing 8.5 ppm PCBs in soil showed 1.16 ppm PCBs (1/7th of that in the soil), and rhubarb grown in the same soil had 0.25 ppm PCBs (1/34th of that in the soil). The Bloomington sludge was much more heavily contaminated with PCBs than the sludge used by Lawrence and Tosine (73), and was spread on land at 25 tons per acre which was about three times the maximum application rate recommended (15,74). In order to protect the public health FDA has recommended to EPA that sludges should not contain more than 10 ppm PCBs on dry weight basis for the application of sludge to agricultural lands (Table 14) (66,75), and EPA adopted this value in its regulations (76). However, municipalities without a significant source of PCBs would be expected to have less than 10 ppm PCBs in their sludges. In a survey of sixteen American cities (14), only two cities, Chicago Illinois, and Schenectady, New York, had PCBs levels over 10 ppm in sludge. Bloomington, Indiana, is an example where very high levels of PCBs were found in sludge - 300 ppm (15). This is because of direct discharge of PCBs waste by Westinghouse Electric Corporation into the city sewerage system which is then concentrated in the sludge. The levels in Schenectady, New York, are high because of the location of two General Electric plants which use large amounts of PCBs in the manufacture of electrical capacitors.

(c) Uptake by Animals: Cattle and other animals ingest soil as well as plants while grazing. Chemical contaminants, especially metals, pesticides, and PCBs, may build up in selected tissue of such animals when sewage sludge is used on land and pastures (6,67,77,78). Although wastewater effluent may present a lesser problem, those from highly contaminated sources may result in the buildup of contaminants in the surface layer of soil similar to that observed with sludges.

Some efforts have been made to utilize sewage sludge as an animal feed supplement because of its nutritive value. Sewage sludge subjected to gamma radiation at a dosage of 1 mega-rad or more to eliminate the risk from pathogens and parasites was used as cattle feed supplement and the tissue accumulation of heavy metals (77) and pesticide residues (77,78) was studied by Smith et al. Pesticide residues were determined in adipose tissue from kidneys. They found that feed consumption was decreased but there was no evidence of toxicity or impaired reproduction. Five of the pesticide residues were significantly elevated by the diet containing 20% sewage sludge. Subsequent feeding on a conventional finishing diet reduced these levels, but not to the levels of the control animals (Table 15).

In the Bloomington, Indiana, incident of contamination of wastewater and sludge by PCBs described in an earlier section (15), PCBs were found in ground beef from cattle which grazed on contaminated lands. The cattle of a farmer, whose pasture had been flooded by a creek which had been contaminated by PCBs, suffered weight loss and one calf was born without pupils in its eyes. The milk fat of another farmer's cow who grazed on sludge-treated pasture was found to contain 5 ppm PCBs - twice the FDA's 2.5 ppm tolerance level. FDA has currently lowered the tolerance level in milk fat to 1.5 ppm, because data developed since 1973 show that PCBs are more toxic than previously believed to be (Table 13) (63,64).

TABLE 14. FDA RECOMMENDATIONS TO EPA ON THE LAND APPLICATION OF SLUDGE (66,75,76)

a. Sludges should not contain more than 20 ppm cadmium, 1000 ppm lead or 10 ppm PCBs on the dry basis.

b. In support of the limits proposed by the W 124/NC 118 Committees of Land Grant Colleges, the maximum total which should ever be added to an average soil (cation exchange capacity of 5-15) is 9 lbs/acre of cadmium and 900 lbs/acre of lead.

c. Crops which are customarily eaten raw should not be planted within three years after the last sludge application.

d. Crops such as green beans, beets, etc. which may contaminate other foods in the kitchen before cooking should not be grown in sludge-treated land unless the sludge gives a negative test for pathogens.

e. Because sewage can be regarded as filth, food physically contaminated with sludge can be considered adulterated even though there is no direct health hazard. Sludge should not be applied directly to growing or mature crops where sludge particles may remain in or on the food.

f. Commercial compost and bagged fertilizer products derived from sludges should be labeled properly to minimize contamination of crops in the human food chain which may result from their use.

TABLE 15. SOME PESTICIDE RESIDUES IN ADIPOSE TISSUE OF CATTLE FED IRRADIATED SLUDGE[a] (77,78) (ppb, Fresh Weight Basis)

Treatment group	p.p'-DDE	Dieldrin	Oxychlordane	TNC	Aroclor 1254
	20	20	0	0	0
Controls	20	<20	0	<10	500
	30	<20	0	<10	500
$\bar{X} \pm \sigma$	23 ± 6	<20	0	<10	333 ± 289
Fed diet containing 20% sludge for 68 days	120	80	70	80	380
	100	50	50	70	960
	90	50	120	70	980
$\bar{X} \pm \sigma$	103 ± 15	60 ± 17	80 ± 26	73 ± 6	1107 ± 237
Fed diet containing 20% sludge for 68 days followed by conventional diet for an additional 56 days	60	50	30	20	600
	20	<20	0	0	500
	60	30	30	20	670
$\bar{X} \pm \sigma$	47 ± 23	33 ± 15	20 ± 17	13 ± 12	590 ± 85
Irradiated dried sludge	40	36	0	0	1440

a. Adapted from G. S. Smith et al. (77).

The accidental feed contamination of dairy cows in Michigan by polybrominated biphenyls (PBBs) illustrates what may happen when excessive quantities of toxic organic chemicals are ingested by animals. PBB levels of 110-2480 ppm were found in body fat of the animals while levels of 44-900 ppm were found in milk fat. The animals had the following symptoms: loss of appetite, eye watering, weight loss, increased frequency of urination, decreased milk production, matting and loss of hair, abscesses, hematomas, abnormal hoof growth, embryo resorption, abortions, stillbirths, deaths shortly after deliveries, delayed deliveries, etc. (79,80).

(d) Uptake by Humans: Although there is no direct evidence of human health hazards from the uptake via food chain of the organic chemicals in wastewater and sludge used in land application, some information is available from two incidents of accidental food contamination by PCBs in Japan and PBBs in Michigan.

(i) Food Contamination by PCBs in Japan: Sporadic outbreaks of a peculiar skin disease characterized by acneiform eruptions and pigmentation of the skin and nails were reported in Japan in 1968. The disease was found to be associated with the consumption of a particular batch of one brand of rice oil. The disease was called Yusho (rice oil disease). The cause of Yusho was traced to a specific batch of rice oil shipped by one company. The oil was found to contain approximately 2000 ppm of Kanechlor KC400, a commercial preparation of PCB containing 48% chlorine. The latency period between ingestion of the oil and onset of clinical symptoms was generally 5-6 months. Elevated serum triglycerides, increased urinary 17-ketosteroid excretion and respiratory distress are some of the physiological abnormalities that were observed in Yusho patients (81). Occupational exposure of PCBs had previously been linked to chloracne and hepatic dysfunction.

(ii) PBB Episode in Michigan: The accidental contamination of Michigan dairy farm animal feed by the polybrominated biphenyl (PBB) compound Fire Master BP-6 in 1973-1974 was followed by illness and death of many cattle which had consumed the PBB-containing feed. Widespread human exposure resulted from consumption of contaminated milk, eggs, meat, and poultry. In response to concerns regarding reports of the appearance of adverse health effects among Michigan dairy farmers exposed to PBB and the possible association of such symptoms to their PBB exposure, Anderson et al. (82) conducted comprehensive clinical and laboratory examinations of PBB-exposed Michigan farmers. A comparable group of Wisconsin farm families who were not exposed to PBB were used as controls. The symptoms noted were neurological (marked tiredness, fatigue, sleepiness, weakness, poor memory, loss of appetite); musculoskeletal (arthritis-like symptoms); and gastrointestinal (abdominal pain, diarrhea and weight loss). In most of the participants in the survey, the symptoms represented a distinct change from their previous health pattern. Statistical analysis revealed that the Michigan group had significantly higher prevalence of the above

mentioned symptoms. No clear relationship can be established between serum PBB level and the presence of any of the symptoms noted. The existing difference could not be explained without considering an etiologic role for exposure to PBBs.

Liver function tests (83) (Table 16) showed that the Michigan group had higher prevalence of abnormal SGOT and SGPT. A clear sex difference was also noted; Michigan men had a higher prevalence of abnormal SGPT and LDH than Michigan women, and a higher prevalence of abnormal SGOT and SGPT than Wisconsin men. Michigan women did not differ from Wisconsin women in prevalence of abnormality of any liver function test. The authors did not observe any relationship between serum PBB levels and liver function tests but they tentatively ascribed the greater prevalence of abnormal SGPT and SGOT among Michigan dairy farm residents compared to the Wisconsin farm residents to the former group's exposure to PBBs.

Consumers who had purchased farm products from both quarantined and nonquarantined farms in Michigan were also surveyed by Lillis et al. (84). The prevalence of liver function abnormalities SGOT and alkaline phosphatase were similar in farmers from quarantined and nonquarantined farms. The prevalence of abnormal SGOT and alkaline phosphatase levels was high in the subgroup of consumers of products from quarantined farms.

These examples are isolated cases of accidental contamination and as such represent effects of acute exposure and may not be representative of potential contamination by organic chemicals of food chains from land application. Nevertheless, they serve the purpose of providing some insight into the effect of consuming these chemicals through food chains and they may be useful in setting standards.

The Curene 442 (MOCA) contamination incident mentioned in an earlier section illustrates how industry can expose general population to unknown risks (23). The residents of the community surrounding the Anderson Development Company in Adrian, Michigan have been exposed to Curene 442 (MOCA), a potential human carcinogen, due to widespread contamination of roadside soil and air, and household dust (Table 4). The contamination is so widespread that Mr. Howard Tanner, Director of the Michigan Department of Natural Resources, in a press release on May 2, 1979, stated that "Citizens should use precaution as our analysis thus far indicates there is a concern for direct human contact with contaminated soils. Possible sources of direct human contact could be in gardens, sandboxes, and playgrounds, in a five-block radius adjacent to the plant, which is located at 1415 East Michigan, Adrian."

The residents of this community have consumed produce grown in the household gardens. However, laboratory analyses by the Michigan Department of Agriculture showed that Curene 442 (MOCA) was not taken up by the plants that were tested as mentioned before. The Michigan Department of Public Health

TABLE 16. LIVER FUNCTION TESTS OF MICHIGAN[a] AND WISCONSIN[b] DAIRY FARM RESIDENTS (83)

	Number examined	SGOT >41		SGPT >45		LDH >225		Alkaline phosphatase >95	
		No.	%	No.	%	No.	%	No.	%
Michigan									
Men	314	40[c]	12.7	49[d,e]	15.6	32[f]	10.2	39	12.4
Women	300	26	8.7	19[d]	6.3	10[f]	3.3	29	9.7
Total	614	66[g]	10.7	68[h]	11.1	42	6.8	68	11.1
Wisconsin									
Men	79	2[c]	2.5	3[e]	3.8	4	5.1	15	19.0
Women	62	2	3.2	1	1.6	0	0.0	5	8.1
Total	141	4[g]	2.8	4[h]	2.8	4	2.8	20	14.2

a. Exposed to PBBs in food chain.

b. Not exposed to PBBs.

c,d,f,g,h. Paired superscripts denote significant difference, $p < 0.005$.

e. Significant difference, $p < 0.01$.

has monitored the urine specimens of randomly selected persons living within a five block radius of Anderson Development Company and found no evidence of Curene 442 (MOCA) in urine of the study participants. The long-term health effects of exposure to Curene 442 (MOCA) on the residents of the community of Adrian, Michigan are not known at present. The Michigan Department of Natural Resources and the Michigan Department of Public Health have formed a blue-ribbon panel of experts from across the nation to assess the risk to the public health of the type of exposure to Curene 442 (MOCA) in Adrian, Michigan.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

The potential health problems associated with the presence of persistent organic chemicals in wastewater and sludge, when applied to agricultural lands, are reviewed. The type and amounts of organic chemicals present in wastewater and sludge, their fate on land, and available control measures are discussed. The potential health effects of organic chemicals on workers/populations who come in contact with them during wastewater treatment, transportation, and/or application are considered.

The review concludes that there is not sufficient information at present to assess the full extent of long-term health risks of exposure to organics in the wastewater treatment plants or at land application sites. Recommendations are made concerning guidelines and further research. Further research is recommended on the uptake of organic chemicals by food crops. Long-term follow-upis also recommended for populations who have had acute short-term exposure to organic chemicals from waste materials.

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