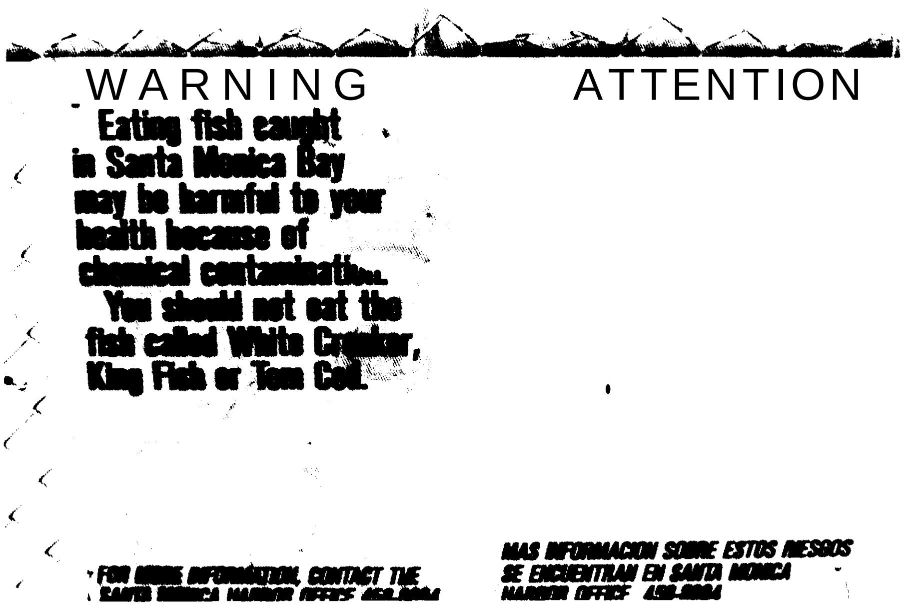

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Chapter 6
Impacts of Waste Pollutants on Human Health

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Chapter 6

Impacts of Waste Pollutants on Human Health

INTRODUCTION

Many substances found in wastes disposed of in marine environments have the potential to produce a variety of acute and chronic human health effects. The likelihood of human exposure to these pollutants depends on their physical, chemical, and biological form; concentration; and persistence or survival. The character of the disposal environment, method of disposal, and nature of environmental pathways leading to human exposure are also important variables.

There are two major contaminant pathways to humans. Contaminants can pass direcdy from contaminated media (water or air) to humans, typically by uptake through the skin or lungs, or through ingestion (e. g., swallowing water). Alternately, they can reach humans *indirectly* by ingestion of plants or animals that have taken up these substances directly or indirectly from contaminated environments. The relative significance of these two kinds of pathways varies for different pollutants.

Indirect exposure from water can be a significant route of exposure to toxic organic chemicals and metals because many of these substances have a capacity to persist in the environment, to concentrate in particular parts of the environment, and to bioaccumulate in certain plants and animals. Direct human exposure to toxic organic chemicals and metals from water is generally less significant because these substances are typically present in water at relatively low concentrations.[2] For pathogens, both direct and indirect exposure can be significant because only small numbers of microorganisms are required to induce disease, and because microorganisms can reproduce in the environment or in infected animals.

Another general distinction can be made between different types of pollutants based on the extent to which they persist or are degraded in the environment. "Conservative" and ''persistent' pollutants (e.g., toxic metals, PCBs) are broken down slowly or not at all, while ''nonconservative' and ''labile' pollutants (e. g., biodegradable or volatile organic chemicals) are rapidly rendered harmless or are removed from the system by environmental processes. Most of the problem substances in marine environments are in the former categories: their environmental persistence enhances their potential to reach and affect humans. Microbial contaminants of both types exist as well; some microbes are killed or inactivated by environmental processes, while others can actually proliferate.

Human health impacts can be associated with three major categories of pollutants that are present in wastes disposed of in marine environments, and that have the potential to reach and cause adverse impacts in humans. These categories are:

1. toxic metals: arsenic, cadmium, lead, and mercury;
2. synthetic organic chemicals: polycyclic aromatic hydrocarbons (PAHs), chlorinated hydrocarbons, and "specialized" chemicals (polychlorinated biphynyls (PCBS), pesticides, dioxins); and
3. human pathogens: viruses, bacteria, fungi, and parasites.

[1] Much of the information presented in this chapter is derived from extensive analyses contained in two contract reports prepared for OTA (205, 409).

[2] Where high concentrations are present, direct exposure of humans to such substances in water can cause significant impacts. Such exposures might be experienced, for example, by bathers swimming at a beach in the immediate vicinity of an industrial discharge or by divers working in highly polluted maters.

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LIMITATIONS OF HUMAN HEALTH EFFECTS DATA

Major impediments exist that limit a thorough evaluation of the human health impacts caused by waste-borne pollutants. Information is lacking on most of the individual substances detected in wastes and there is often uncertainty or controversy surrounding those for which there are data. In addition, it is difficult to accurately predict the behavior of a substance based only on data for chemically similar substances. An accurate assessment is also hindered by the complexity of most wastes, which are typically contaminated by a mixture of potentially harmful substances. Existing data typically allow at most an assessment of *acute, short-term* impacts associated with a particular waste; it is rarely possible to adequately assess *chronic, long-term* effects.

Moreover, studies of the environmental or ecological impacts of individual chemicals introduced into the environment through waste disposal rarely measure or sufficiently consider the potential *human health effects.* In fact, the human health risks associated with exposures to the vast majority—90 percent or more—of all chemicals found in different wastes are unknown (386). Knowledge about the human health effects of environmental pollutants generally comes from studies of only a few toxic compounds, such as mercury, cadmium, and PCBs (409); and these effects are often recognized only after large-scale occupational exposure, industrial accidents, or massive discharges of waste into the environment.

The accumulated knowledge in the field of toxicology is based primarily on experimental work with laboratory mammals. Thus, estimating human health risks from the disposal of chemical compounds in marine environments is generally based on extrapolating information on the toxicity of specific chemicals to laboratory mammals to the concentrations observed in marine organisms or humans. The estimates must also attempt to account for the persistence of such substances in the environment and their tendency to bioaccumulate or to biomagnify in marine organisms that might be consumed by humans. Public health information on human pathogens is largely derived from investigations of past incidents and, more rarely, on prospective epidemiological or clinical efforts.

TOXIC METALS

General Characteristics

Metals are chemical elements and as such cannot be destroyed or broken down through treatment or environmental degradation. However, a number of environmental processes—both chemical and biological-can alter the mobility and bioavailability of metals,

In general, toxic metals (including arsenic, beryllium, cadmium, chromium, cobalt, copper, lead, mercury, molybdenum, nickel, selenium, and zinc) are of potential concern whether they are found in wastes that will be disposed of on land or in the ocean. With respect to human health impacts arising from disposal of wastes in the marine environment, four metals are of primary concern: arsenic, cadmium, lead, and mercury. These are particularly important because of their known toxicity to humans and their presence in relatively high concentrations in wastes disposed of in estuaries and coastal waters. Metals of secondary concern include chromium, copper, and selenium. Other toxic metals are present in much lower concentrations both in wastes and in regions of the marine environment that are likely to lead to human exposure (409).

In marine environments, most dissolved metals are rapidly adsorbed and remain bound to particulate material that eventually settles out of the water column and is incorporated into sediments. However, some metals (e. g., cadmium, copper, nickel, and zinc) can be slowly—over a period of months or years—released from the sediment's oxidized surface layer and sublayers (124). In addition, metals can be released through other chemical and biological changes or processes, for example, by changes in salinity that commonly occur in estuarine waters. The action of microorganisms can also mobilize metals: for example, bacteria in sediments can convert slightly toxic inorganic mercury to the highly toxic and volatile methyl mercury (26). Finally, the burrowing of animals into sediments (bioturbation) and physical processes such as storms can release metals from sediments through oxidation and direct physical resuspension (709).

Pathways to Humans

Indirect pathways to humans vary with the particular environment and method used for disposal. In marine environments, consumption of contaminated seafood is generally the major route of human exposure to metals. *Direct* human exposure to metals is usually less important because they generally attain very low concentrations in the water column (409). However direct exposure resulting from volatization of certain metals (e. g., mercury, arsenic, and lead) due to their methylation by microorganisms, or direct exposure to marine waters with high concentrations of metals, would be a concern.

Bioaccumulation and biomagnification[3] are important processes that largely determine the potential for indirect human exposure to toxic metals and organic chemicals that result from marine waste disposal. Marine organisms, especially benthic organisms, can bioaccumulate metals by filtering water during feeding or swimming, ingesting particulate matter onto which such substances are adsorbed, or ingesting other contaminated organisms (46,232 ,260). Bioaccumulation generally increases as the degree of water or sediment contamination increases, but it varies considerably among metals, species of marine organisms, and types of sediment.

Biomagnification of a metal can result in the stepwise increase in an organism tissue concentration of several orders of magnitude or more, and hence represents a major potential pathway for human exposure. According to available evidence, most toxic metals do not biomagnify into higher trophic levels of the marine food chain (33,260). However, methyl mercury, and perhaps selenium[4] and zinc, are important exceptions to this rule.

Of the metals of primary concern, cadmium and mercury have significant potential for transport to humans through consumption of contaminated seafood (table 8). Arsenic is largely converted to nontoxic forms by marine organisms (129), and neither arsenic nor lead have been shown to accumulate significantly in seafood (409).

Even when bioaccumulation is not a factor, significant quantities of metals can concentrate in the gut or gills of marine organisms without actual absorption into the tissues. This is especially true for shellfish that filter large quantities of seawater and ingest solid matter during feeding (e. g., oysters, clams, mussels). Because people generally eat these organisms in their entirety, toxic substances can be passed to humans even in the absence of any actual bioaccumulation. This mechanism probably accounts for most instances of shellfish contamination involving metals that do not bioaccumulate.[5]

Potential and Actual Human Health Impacts

Toxic metals are capable of inducing a variety of human health effects—lethal and sublethal, acute and chronic. Some of the known properties and effects of exposure to the metals of primary concern in marine environments are summarized in table 8.

Acute environmental effects attributable to toxic metals may occur if concentrations are sufficiently high. Although documentation of human poisoning from consuming seafood contaminated with toxic metals is uncommon, there have been several well-known, catastrophic events. In Minamata, Japan, for example, over 100 people died and 700 others suffered severe, permanent neurological damage after consuming shellfish contaminated by industrial discharges of methyl mercury into Minamata Bay (128). A similar, though less severe, event occurred in Niigata, Japan in 1965 (550).

[3] In this context, the term bioaccumulation refers to the process whereby a substance enters an aquatic organism, either directly from the water through gills or epithelial tissue, or indirectly through consumption of other organisms. Biomagnification refers to the resultant process whereby tissue concentrations of bioaccumulated substances increase as the material is passed up through more than one trophic level in the food chain (260).

[4] High levels of selenium have been detected in the tissues of at least two species of marine birds: Texas laughing gulls in Galveston Bay (268), and California scoters in San Francisco Bay (424).

[5] This phenomenon applies equally to organic chemicals and pathogens, as discussed below.

Table 8.—Properties and Effects of Metals of Primary Concern in Marine Environments

	Arsenic	Cadmium	Lead	Mercury
Bioaccumutation	Low except in some fish species	Moderate	Low or none	Significant (methylated form)
Biomagnification	Low or none	Low or **none**	Low or none	Significant (methylated form)
Properties	Metallic form: insoluble Readily methylated by sediment bacteria to become highly soluble, but low in toxicity	Metallic form: relatively soluble Not subject to biomethylation Less bioavailable in marine than in fresh water Long biological residence time Synergistic effects with lead	Generally insoluble Adsorption rate age-dependent, 4 to 5 times higher in children than adults Synergistic effects with cadmium	Metallic form: **relatively insoluble** **Readily methylated by sediment bacteria to become more soluble, bioavailable, persistent, and highly toxic**
Major environmental sink	Sediments	Sediments	Sediments	**Sediments**
Major routes of human exposure:				
Marine environments	**Seafood: very minor route, except for some fish species**	Seafood contributes == 10%. **of** totai for general population	Seafood comparable to other food sources	Seafood is primary source of human exposure
Other environments	**Inhalation: the major route**	Food, primarily grains	**Diet and drinking water**	Terrestrial pathways are minor sources in comparison
Health effects	Acute: gastrointestinal hemorrhage; loss of blood pressure; coma and death in extreme cases Chronic: liver and peripheral nerve damage; possibly skin and lung cancer	Emphysema and other lung damage; anemia; kidney, pancreatic, and liver impairment; bone damage; animal (and suspected human) carcinogen and mutagen	Acute: gastrointestinal disorders Chronic: anemia; neurological and blood disorders; kidney dysfunction; joint impairments; male/female reproductive effects; teratogenic	Kidney dysfunction; neurological disease; skin lesions; respiratory impairment; eye damage; animal teratogen and carcinogen
References [a]	Doull, et al., 1980 Barrington, et al., 1978 O'Connor and Kneip, 1986 Woolson, 1983	Chapman, et al., 1968 Nriagu, 1981 O'Connor and Kneip, 1986 Wiedow, et al., 1982	Callahan, et al., 1979 Heltz, et al., 1975 Kneip, 1983 NAS, 1980 O'Connor and Kneip, 1986 O'Connor and Rachlin, 1982	Grieg, et al., 1979 Kay, 1984 Nriagu, 1979 Windom and Kendall, 1979

[a]See list of references at end of report.

SOURCE: Office of Technology Assessment, 1987

Other events involving metal contamination of food sources (though not seafood) have occurred. These include dietary transport of lead and cadmium from the application of sewage sludge to agricultural lands (470,47 1); and the pollution of Japanese rice paddies by industrial cadmium discharges, which resulted in 60 deaths (404).

Substantial laboratory evidence documents the potential for lethal and sublethal *chronic* effects to result from exposure to metals contributed by waste disposal activities. However, our capacity to detect chronic impacts in the field is limited, and this is in part responsible for the paucity of data documenting such human health effects.

Mercury is of special concern because it is easily taken up by humans through a diversity of exposure routes, including inhalation, ingestion, and through the skin. The source of mercury responsible for contamination of marine organisms differs among the various marine waters. In the open ocean, natural sources of mercury predominate, whereas in some estuaries and coastal waters, inputs from land-based sources are commonly the major source of contamination. In fact, marine organisms from polluted estuaries typically contain five or more times as much mercury as marine organisms from relatively clean estuaries (702).

Ingestion of contaminated shellfish and finfish, especially long-lived predatory fish such as tuna, is the primary route of human exposure to mercury (202,702). Again, however, in open-ocean fish mercury is generally attributable to natural sources, while shellfish contamination is typically more closely correlated with waste disposal.

Cadmium is used extensively in metal electroplating and found in a wide variety of wastes. It is more mobile than most other toxic metals. Large-scale cadmium contamination of estuarine waters by industrial and municipal wastewater discharges has occurred in some urban areas, for instance in the Hudson River estuary, and this has caused significant contamination of marine food chains (272,409). For example, studies show that shellfish harvested near an industrial outfall formerly used to discharge cadmium wastes contained levels high enough to induce acute cadmium poisoning in an unwary consumer or urban fisherman (refs. 229,696; also see box N later in this chapter). Other studies of the entire Hudson estuary found that moderate consumption of shellfish could lead to exposure exceeding recommended safe levels (41 1).

The actual mechanism by which cadmium is transported through the marine food chain is controversial. Some investigators have found that cadmium present in sediments of some urban embayments is readily taken up by organisms, and that contaminated sediments represent the most likely source of human exposure (229). However, others suggest that sediments are not a significant contributor of cadmium even to contaminated organisms harvested from marine waters near urban-industrial areas (491).

TOXIC ORGANIC CHEMICALS

General Considerations

Some 65,000 chemical compounds are used in industry worldwide (386). Of these, approximately 10,000 are used regularly in one or more industrial processes; about 1,000 new chemicals are introduced into commerce each year (23 1). Clearly, individual evaluation of the health effects of each of these compounds is a hopeless enterprise. For several broad categories of industrial chemicals, figure 24 shows the paucity of data available on which to base health hazard evaluations.

Organic chemicals vary considerably with respect to their behavior in natural environments. Some chemicals accumulate in organisms; others do not. Some decompose rapidly if exposed to light, heat, or water; others are highly persistent. Some compounds may be metabolized by organisms into other compounds that may be more or less toxic than the original compound; others resist biodegradation. Toxicities may vary from one organism to another, and toxic levels may also be affected by the presence of other compounds, producing synergistic or antagonistic effects.

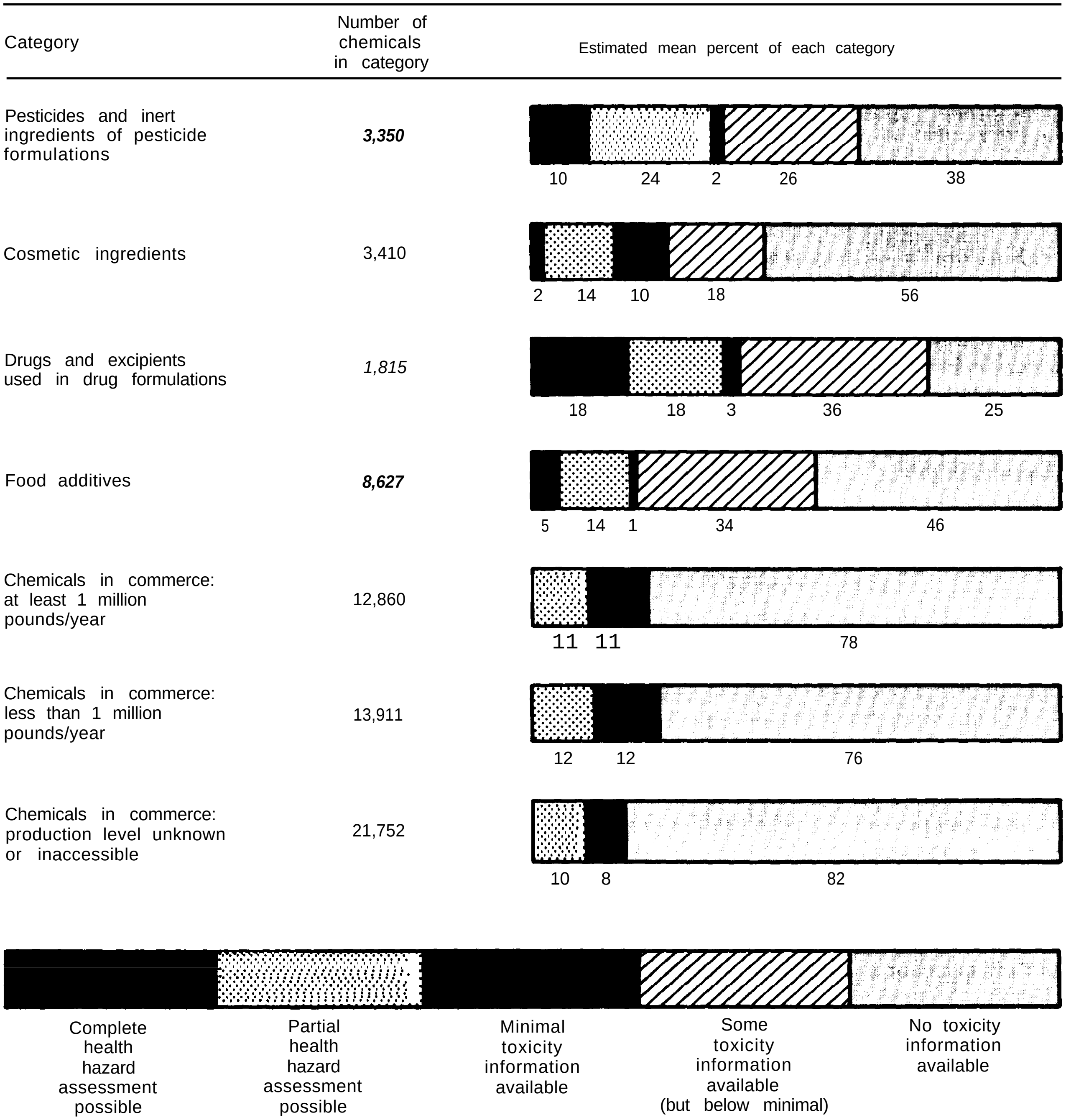
Given this complexity, it is essential to invoke some system to simplify classification if a health hazard evaluation is to become manageable. One approach is to classify compounds according to how they behave in the environment, that is, on the basis of environmental fate. This approach can be used to reduce the size of the chemical universe down to those substances that have a potential to *reach* humans; information on human health effects would then only need to be developed for this subset.

Several relatively well-understood relationships exist between chemical properties of organic compounds and their fate in natural environments:

Chemical Property:	*Related to:*
Solubility in water	Adsorption, route of absorption, mobility
Vapor pressure volatility)	Atmospheric mobility', environmental persistence
Solubility in animal tissue	Bioaccumulation potential, adsorption by organic matter or sediments. persistence in organisms

[6]Organ ic chemicals possess a molecular skeleton made of carbon and hydrogen and generally contain relatively few other elements, such as oxygen, nitrogen, or chlorine. Chlorine-containing organic compounds are referred to as ' 'chlorinated. " Metals or metal-containing substances are usually termed " inorganic, although in some cases metals can be chemically bound to organic compounds (e. g,, methyl mercury).

Figure 24.—Ability To Conduct Health-Hazard Assessment of Substances in Seven Categories of Chemicals in Use



SOURCE: National Academy of Sciences, *Toxicity Testing: Strategies To Determine Needs and Priorities* (Washington, DC: National Academy Press, 1984).

Using a scheme based on determinants of environmental fate such as these, it is possible to identify, for example, a class of compounds with low water volubility and high tissue volubility (e. g., PCBs, dioxins) that is likely to persist for long periods in the environment and bioaccumulate in organisms. Another class with the characteristics of high volubility and high volatility (e. g., chloroform, toluene) is likely to have low potential for accumulation in the food chain, but may pose a hazard to humans from inhalation or ingestion in drinking water. These considerations form the basis of the classification of organic chemicals used in this section (table 9).

Pathways to Humans

The most serious risks to human health are generally posed by those organic chemicals that are toxic, persistent, and have some means of reaching humans (i. e., present in significant concentrations in what has been termed the human exposure zone). As was the case for metals, humans can be exposed to organic chemicals either *directly* from the water (by absorption through the skin, by drinking contaminated water, or by inhaling contaminated air), or *indirectly* through ingestion of contaminated plants or animals.

In marine environments, many organic chemicals partition into sediments or onto the water's upper surface (the surface microlayer), where they are potentially available to marine plants and animals; this can provide an indirect pathway to humans through ingestion of contaminated seafood. Direct human exposure to organic chemicals is less common because these substances generally can be present in the water at only very low concentrations, although in some cases they may be of substantial concern.

As was the case for metals, the consumption of contaminated seafood is the primary pathway for human exposure to most organic chemicals in wastes disposed of in marine environments. Indeed, compounds such as PCBs and DDT have been shown to accumulate in humans through consumption of contaminated seafood (249,409),

Not surprisingly, the importance of bioaccumulation and biomagnification varies greatly for different organic chemicals and for different organisms. Several classes of organic chemicals, particularly those that are relatively insoluble in water, have a high bioaccumulation potential because of their volubility in animal tissue. Some of these organic compounds, including PCBs, benzo[a]pyrene, naphthalenes, and chlorinated pesticides (e. g., kepone, mirex, and possibly DDT), also appear to have a potential for biomagnification by marine organisms.

Other compounds that bioaccumulate but probably do not biomagnify include chlorinated phenols and benzenes, and most PAHs. However, there is relatively little information on the long-term fate and behavior of most organic compounds in aquatic environments (260).

Potential and Actual Human Health Impacts

Few documented cases of human health impacts from waste-derived organic chemicals in marine environments exist.[7] However, the potential for such exposure and effects clearly exists in the United States. Numerous estuarine and coastal areas—e.g., New Bedford Harbor, New York Harbor, and portions of Puget Sound—are sufficiently contaminated with toxic chemicals to preclude the harvest of fish and/or shellfish (box L; refs. 211 ,507). Commercial and recreational fishing for striped bass, bluefish, tautog, and eels has been curtailed in large portions of the New York Bight's apex due to high concentrations of PCBs and other organic compounds (28,30,237).

PCBs and PAHs are widely distributed in inland and coastal sediments and have been found in deep ocean sediments as well (62,325,484). PCBs and several other highly persistent and toxic chemicals (e. g., DDT) have been banned from further production or use in commerce in the United States. It can be expected, therefore, that the sediment concentrations and body burdens of these toxic compounds will probably decrease gradually over time

[7] Several cases involving land-based food sources have been reported, The most infamous is a disease outbreak in Japan, known as the Yusho incident, that was caused by the leakage of PCBs (in combination with dibenzofurans) from an industrial heat exchanger into a rice oil manufacturing process, Yusho symptoms included reduced birthweights and skin disorders such as chloracne and hyperpigmentation (287).

Table 9.—Properties and Effects of Major Classes of Organic Chemicals in Wastes Disposed of in Marine Environments

Chemical class	Major examples	Properties	Primary routes to humans	Health effects	References[a]
Low molecular weight hydrocarbons	**Benzene** **Toluene** **Xylene**	Volatile Biodegradable Low bioaccumulation potential	Inhalation Drinking water	Benzene: central nervous system (CNS) effects, blood disease, leukemia Toluene: possible CNS effects, low toxicity Xylene: irritant; teratogen	Callahan, et al., 1979 Doull, et al., 1980 NAS, 1977 O'Connor and Kneip, 1988 Snyder, et al., 1984
Low molecular weight chlorirlated hydrocarbons	Chloromethanes: carbon tetrachloride (CTET) chloroform methylene chloride	**Volatile** **Lipid-insoluble** **Low bioaccumulation potential** **Some (e.g., CTET and chloroform) are persistent; others (e.g., methylene** chloride) are readily biodegraded	**Inhalation** **Drinking water**	CTET and chloroform: liver, kidney, blood, and gastrointestinal disorders; liver and kidney cancer Methylene chloride: possible CNS effects	Callahan, et al., 1979 Doull, et al., 1980 O'Connor and Kneip, 1988 Thorn and Agg, 1975
	Trichloroethylene, tetrachloroethylene, tetrachloroethane	Volatile Lipid-insoluble Low bioaccumulation **potential**	Inhalation **Drinking water**	All: CNS effects, liver toxicity Tri- and tetrachloroethy lene: liver cancer	Callahan, et al., 1979 Doull, et al., 1980 Sittig, 1985
	Vinyl chloride	Volatile Low bioaccumulation **potential**	**Inhalation**	Animal and human carcinogen; liver toxicity	Doull, et al., 1980
	Chlorobenzenes	Range of volatilities Lipid-soluble Significant bioaccumulation potential	**Food (including seafood)**	Hexachlorobenzene: carcinogen	Doull, et al., 1980 O'Connor and Kneip, 1988
Chlorinated pesticides	Cyclodiene pesticides: **aldrin,** dieldrin, heptachlor, chlordane DDT and metabolizes Chlorinated phenoxyacetic compounds (2,4,5-T; 2,4-D) Hexachlorocyclohexanes: lindane, BHC	Nonvolatile High bioaccumulation potential Moderate to high toxicity Most are highly persistent	Food (including seafood)	**Known or suspected human carcinogens; neurotoxic effects; chloracne and other skin diseases**	Doull, et al., 1980 Mrak, 1989 NAS, 1977 Sittig, 1985 Walker, et al., 1989
High molecular weight chlorinated hydrocarbons	Polychlorinated biphenyls (PCBs) Chlorinated dioxins **TCDD)** **Chlorinated dibenzofurans**	**Nonvolatile** **High bioaccumulation potential** **Moderate to high toxicity** **Highly persistent**	**Food (including seafood)**	All: **neurological, liver, and skin disorders** **PCBs: tumor promoters or carcinogens** **TCDD:** highly carcinogenic	Kimbrough, et al., 1975 Koibye and Carr, 1984 Murai and Juroiwa, 1971 Poiger and Schlatter,1983
Aromatic hydrocarbons	**Phthalate esters (e.g., DEHP)** **Polycyclic aromatic hydrocarbons (PAHs)**	Low to moderate volatility Highly insoluble Range of bioaccumulation potential Low to moderate toxicity	Food (including seafood)	Phthalates: many are teratogens DEHP: possible carcinogen PAHs: many (e.g., benzo(a)pyrene) are carcinogens; some are teratoaens	FDA, 1974 Giam, et al., 1978 MacLeod, et al., 1981 NAS, 1977

[a]See list of references at end of report.

SOURCE: Office of Technology Assessment, 1987.

Box L.—Public Health Advisories

One measure of the extent of contamination of seafood with potentially harmful levels of toxic substances (e.g., metals or organic chemicals) or microorganisms is the number of public health advisories that have been issued warning against consumption of seafood harvested from particular areas.* Unfortunately, there is no readily available national registry of such advisories (which are typically issued at the State level). However, a survey of coastal States to obtain this information is being undertaken by the National Marine Pollution Progam Office at the National Oceanic and Atmospheric Administration (R. Landy, NOAA, pers. comm., 1986).

While not yet complete, the survey has compiled information on about 40 public health advisories specifically involving toxic metals or organic chemicals (not contamination with microorganisms) that have been issued by coastal States. (Unfortunately, the data do not distinguish between fresh and marine waters or organisms.) Shown below is a preliminary listing of these advisories, broken down by the particular metal or organic chemical involved. Also listed are some of the waterbodies for which these advisories have been issued, most (but not all) of which are in estuaries or coastal waters (figure 25 illustrates the extent of advisories in the New York-New Jersey area). These advisories also demonstrate the importance of seafood consumption as a potential source of human exposure to particular classes of chemicals.

This type of effort represents an essential link in documenting the potential impacts associated with the input of pollutants that are of public health concern into estuarine and coastal marine waters. Further compilation and centralization of such data at both national and regional levels would play a useful role in furthering our understanding of human health risks posed by waste disposal and other activities affecting marine environments.

Substance	*Number of health advisories*
Mercury	7
Selenium	2
Heavy metals**	1
Chlordane	2
DDT	6
Pesticides**	2
PCBs	16
Dichlorobenzene	1
Tetrachlorobenzene	1
Dioxin	1
PAHs	1

Some waterbodies in which public health advisories have been issued:

- San Francisco Bay Delta Region and Santa Monica Bay, CA
- Baltimore Harbor, MD
- Hudson River, New York Harbor, Newark Bay, Lower Passaic and Hackensack Rivers, and Arthur Kill, NJ
- Inner New York Bight and most of Long Island Sound
- Duwamish River and Puget Sound, WA

*Advisories might be issued on any of several bases, for example, if tissue samples of shellfish were found to contain levels of toxic metals or organic chemicals that exceeded U.S. Food and Drug Administration action [illegible] or if [illegible] bacteria [illegible] State water quality criteria.

**Unspecified or multiple substances.

(57,519).[8] Indeed, recent evidence shows such a decline along the west coast of the United States (340).

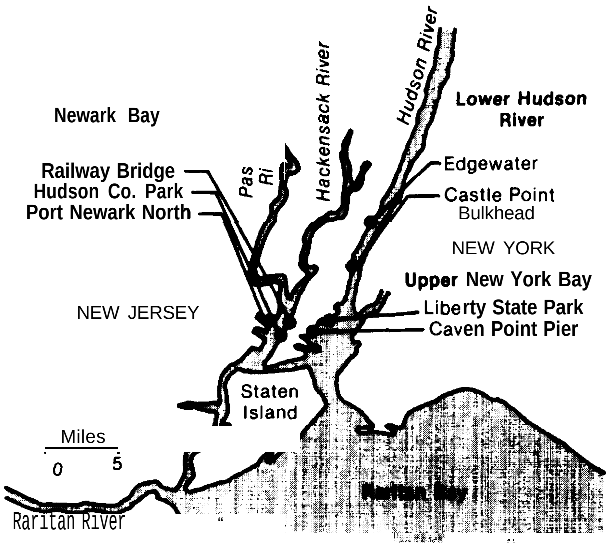
Direct exposure of humans to organic chemicals present in marine waters is possible in places where industrial discharges are located near bathing beaches. For example, a wastewater discharge from a New Jersey pharmaceutical firm, which enters marine waters about 2,500 feet from shore, has been identified in bioassays as the most mutagenic industrial discharge in the State (T, Burke, New Jersey Department of Health, pers. comm., 1986) The wastewater from a Florida paper mill discharged into the Amelia River estuary has been found to be the most toxic among the State's nine mills (8). In neither case, however, has an actual effect on the health of bathers been demonstrated.

[8]However, the manufacture and use of many of these chemicals have not been curtailed in other countries; in addition, existing stocks of some of these chemicals continue to pose major disposal problems,

Classes of Organic Chemicals

To simplify the evaluation of organic compounds, they can be classified on the basis of similarities in their chemic~ structure, physicochemi-

Figure 25.—New York Bay-Newark Bay Fishing Sites and Advisory Areas



The PCB advisory for limited consumption of striped bass and bluefish applies to the coast and all the rivers and tributaries shown. Sale for human consumption of striped bass and American eel from most of these rivers is also prohibited.

SOURCE: T. Belton, et al., "Urban Fishermen: Managing the Risks of Toxic Exposure," *Environment* 28:19-20,30-36, November 1966.

cal properties (e. g., volatility, tissue volubility), and molecular weight. Chemicals having similar characteristics often tend to exhibit similar environmental fates or behavior, and therefore may follow similar pathways to reach humans. In some cases (though less predictably), compounds in the same group may also have similar toxicity characteristics. It should again be emphasized, however, that although such grouping of organic compounds helps determine their potential for significant human exposure, each compound must still be examined individually for specific environmental and health effects.

Table 9 lists the primary classes of organic chemicals that have some potential for reaching humans and inducing adverse health effects. Chlorobenzenes, chlorinated pesticides, high molecular weight chlorinated organic compounds, and aromatic hydrocarbons are of major concern in marine environments due to their ability to bioaccumulate in organisms. While wastestreams containing many of these compounds are specifically prohibited from ocean dumping, the major pathway by which they enter marine environments is as trace contaminants in industrial wastewater effluents, sewage sludge and effluent, and dredging spoils.

Clorobenzenes exhibit a range of volatilities and tissue solubilities (and therefore bioaccumulation potential), dependent primarily on the degree of chlorination. Of all the low molecular weight chlorinated hydrocarbons, chlorobenzenes pose the greatest risk of transport to humans through marine or terrestrial food chains.

Cldorinatedpesticides are significant because of the high risk of human exposure through consumption of contaminated seafood. They strongly associate with organic matter and sediments, where they are readily available to marine organisms. Their high molecular weight and complex, chlorine-containing structures make these compounds very resistant to degradation by bacteria or the metabolic systems of higher organisms. This class of substances exhibits a range of toxicities, from several cyclodiene pesticides that show adverse effects at the lowest doses tested (682) to DDT and related compounds that have moderate toxicity to humans and laboratory animals. Most of these compounds are known or suspected carcinogens.

Chlorinated organic compounds include PCBs dioxins, and dibenzofurans. These compounds generally share the same properties described for the chlorinated pesticides: low volatility, generally high bioaccumulation potential, strong ability to bind to organic matter and sediments, and high resistance to degradation by bacteria or the metabolic systems of higher organisms.

PCBs are actually a group of over 200 individual compounds possessing unique chemical and toxicological properties (494). PCBs are accumulated by marine organisms with very high efficiency. For example, one study found 85 to 95 percent assimilation of PCBs across the gut of striped bass (447). The ubiquity of PCBs in the environment and their extreme persistence and toxicity to marine and terrestrial organisms, led to a ban on their production in the United States in 1979.

Dioxins and dibenzofurans (the most well-studied of which are 2,3,7,8-tetrachlorodioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF)) are found as contaminants of numerous chemical preparations (467). Both sets of compounds are quite tissue-soluble, and are therefore easily bioaccumulated to high levels. TCDD and TCDF are among the most toxic compounds known and can produce lethal effects at low doses in aquatic organisms and birds (191 ,365).

Aromatic hydrocarbons include phthalate esters, which are common contaminants in water, sediment, and marine organisms (72) as well as in various types of wastes, especially sewage (73). The most common are diethylhexyl phthalate (DEHP) and dibutyl phthalate (DBP). Phthalate esters have low water solubilities, tightly adsorb to sediment particles, and are not readily degraded through biological activity (72 ,541). Chronic effects from exposure to phthalate esters include reduced weight gain, enlarged livers and kidneys (381), and an increased incidence of liver cell cancers (274).

Polycyclic aromatic hydrocarbons (PAHs) are derived from petroleum and other chemical processes and constitute most of the ‘ ‘oil and grease regulated as a conventional pollutant under the Clean Water Act. Major sources to marine environments include spills and routine releases from ships, natural seepage, and municipal wastewater, sewage sludge, dredged material, and runoff from urban areas (409). PAHs are readily adsorbed by suspended particulate and bottom sediments, where they persist and can accumulate to levels as high as 1 percent (10,000 parts per million) in highly industrialized areas such as New York Harbor (325).

Marine organisms, particularly mollusks, have a high potential for bioaccumulating PAHs, and they can achieve tissue levels far in excess of water concentrations and roughly comparable to sediment concentrations (409). Certain PAHs (e. g., benzo[a]pyrene and naphthalenes) can also biomagnify in higher level predators of the marine food chain (260). Disposal of wastes at sea is considered the most likely source of PAHs to marine waters; subsequent transport of PAHs to humans can then occur through the food chain (409). How seafood consumption compares to other sources of PAH exposure is not well-understood, however, so the significance of PAH contamination of seafood as a source of exposure to humans is uncertain.

HUMAN PATHOGENS

General Considerations

Essentially all wastes that are disposed of in the marine environment either contain microorganisms or have the potential to modify the microbial community at the disposal site. Among the microorganisms entering the marine environment through waste disposal, or induced to proliferate as a result of such activity, are a variety of *human pathogens,* microorganisms that are capable of inducing human disease (box M).

Human pathogens in the marine environment come primarily from discharges of raw sewage and from sewage sludge and wastewater effluent from sewage treatment plants. For example, it is estimated that about 40 million gallons of raw sewage are discharged daily into the Hudson and East Rivers of New York City.[9] Pathogens are also found in domestic and commercial food wastes, animal wastes, and biological wastes from hospitals and laboratories, many of which are discharged to surface waters or sewage treatment plants. Where combined sewer systems are employed, overflows during times of heavy precipitation can also be a significant source of pathogens. In rural areas, most bacterial contamination comes from non-urban runoff, animal wastes, poor septic systems, and poorly treated sewage discharges. Finally, the marine environment itself is a source of pathogens, because some pathogens naturally occur and propagate in marine waters.

In the United States, the most important waste-borne agents of human disease are viruses and bacteria, with respect to both their concentrations in wastes and the environment, and the incidence of disease attributable to them.[10] Enteric

[9] This discharge is scheduled to be halted in 1987 when a new secondary treatment plant is completed (G. Lutzic, New York City Department of Environmental Protection, pers. comm., 1986)

[10] However, in some parts of the world pathogens from other classes can be very important The World Health Organization has indicated that the parasitic helminth *Schistosoma* is second only to malaria in causing disease and death in the tropics (232)

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viruses are especially significant with respect to disposal of wastes in water, since they are ideally suited to be spread by contact with contaminated water (205).

Pathways to Humans

Both direct and indirect exposure pathways can be significant for pathogens because only a small number of organisms are required to induce disease, and because they can reproduce in wastes, contaminated media, or infected organisms. Several properties of pathogens are important in determining their potential to pose risks to human health.

Survival

A growing body of evidence indicates that some bacteria, including a number of known human pathogens, may persist in the marine environment for periods of many months or longer in a nonculturable, but virulent form (205,366). For example, the agent responsible for an outbreak of cholera along the Gulf coast of Texas appears to have persisted for at least 5 years in coastal waters (35). In addition, many viruses and parasites are extremely resistant to environmental inactivation or destruct ion.

Viruses and bacteria strongly adhere to particulate matter, which provides a degree of protection and increases their survival in sediments (183). Concentrations of enteroviruses may be 10 to 10,000 times greater in coastal sediments than in the overlying water; most pathogens are concentrated in the surface layers of bottom sediments (197). Subsequent dredging of these sediments may increase the concentrations and availability of human pathogens in the areas where dredging or disposal of dredged materials takes place (203,204). ”

A number of human pathogens appear to survive better in estuarine and other coastal environments than in the open ocean (253). However, in some cases, the colder temperature of the open ocean, especially bottom waters beyond the continental shelf, can actually enhance the survival of some pathogens, although it also retards growth (16),

Propagation

Different classes of pathogens have different requirements for propagation. In the absence of an appropriate host, viral or parasitic propagation generally cannot occur, so there are no mechanisms available for increasing the number of viruses in sewage material or the marine environment; they can, however, become concentrated in sludge or sediment. Bacteria introduced through wastes have the potential to replicate and increase their numbers, but this potential has not been well-studied for most organisms. Some pathogenic bacteria that naturally occur in the marine environment are fully capable of propagation (e. g., certain species of *Vibrio)*.

Exposure and Infection

For viruses and microorganisms present in the marine environment to exert an impact on human health, they must both reach and infect humans. The ability of microorganisms to infect humans depends on numerous factors, including the minimum infective dose. As few as 10 to 100 bacteria, or a single virus, are capable of inducing infection and disease under the appropriate conditions (205). Moreover, the tendency for viruses and bacteria to adhere to particulate matter increases the risk of exposure and infection in two ways: 1) survival is enhanced through the protection the particles provide; and 2) because particles literally serve to ‘ ‘collect’ viruses and bacteria on their surfaces, a single ingested particle can contain a large dose of microorganisms. The concentration of viruses and bacteria in sediments also increases the potential for their uptake by shellfish.

Potential and Actual Human Health Impacts

Shellfish-Borne Disease

Large areas of estuarine and coastal waters have been closed to shellfishing and/or finishing because they are contaminated with sewage-derived microorganisms in excess of Federal standards (see box N). While such closures have largely eliminated

]1 For example, a total restriction on shell fishing has been imposed in estuarine waters around a dredging project near Cape May, NJ, because disturbance of the sediments was shown to cause elevated densities of coliform bacteria in the water (J. Staples, New Jersey Department of Environmental Protection, cited in ref. 10),

Box B.—Exposure to Toxic Chemicals and Pathogens Through Seafood

The risk of human exposure to toxic chemicals or pathogens through consumption of [illegible] seafood is growing, and increasing numbers of experts are questioning the adequacy of current programs designed to address this risk [illegible]. The [illegible] to both commercially and recreationally harvested seafood and to coastal areas in all parts of the country. Of particular concern are urban recreational fishing and illegal commercial harvesting, which are widespread practices even in areas for which health advisories or bans on fishing have been issued.

The U.S. Food and Drug Administration (FDA) has authority to set and enforce allowable levels of toxic substances in food or food products, including seafood. Table 10 lists all of the substances for which FDA has [illegible] levels in fish or shellfish, and indicates how much of each substance must be present in an organism's edible tissues before an enforcement action or seizure is authorized (termed the "action level"). While the list includes a fairly comprehensive list of pesticides, it includes only one metal (methyl mercury) and one other toxic organic chemical (PCBs). No action levels have been developed for other substances of concern, such as PAHs, cadmium, or [illegible].

The National Marine Fisheries Service of the U.S. Department of Commerce is the primary Federal agency authorized to inspect seafood harvested for commercial use. The activity of this largely voluntary inspection program has declined in recent years, despite increases in both total and per capita seafood consumption in the United States. In 1983, the service inspected 867 million pounds of fish, almost 19 percent of all that was consumed that year; in 1985, however, inspection had dropped to 645 million pounds, 13 percent of the total consumed (457).*

Some sampling of pollutant levels in fish and shellfish for research purposes also takes place (see ch. 5; ref. 109). These studies have in numerous cases revealed tissue levels of certain pollutants in excess of FDA action levels (29,31). They also reveal the lack of a concerted and coordinated program of routine monitoring that involves a sufficient number of species and individual samples to provide meaningful information on the nature of risks posed by seafood consumption.

Table 10.—FDA's Criteria for Initiating Enforcement Actions Against Seafood

Substance	Action level	Type of food (edible portion only)
Methyl mercury	1.0 ppm	Fish, shellfish, crustaceans, other [illegible]
PCBs[a]	2.0 ppm	Fish and shellfish
Aldrin	0.3 ppm	Fish and shellfish
Chlordane	0.3 ppm	Fish
Dieldrin	0.3 ppm	Fish and shellfish
DDT, DDE, & TDE[b]	5.0 ppm	Fish
Endrin	0.3 ppm	Fish and shellfish
Heptachlor and heptachlor epoxide	0.3 ppm	Fish and shellfish
Kepone	0.3 ppm	Fish and shellfish
	0.4 ppm	Crabmeat
Mirex	0.1 ppm	Fish
Toxaphene	5.0 ppm	Fish

[a]The value for PCBs is a tolerance for unavoidable [illegible] substances.
[b]DDE and TDE are toxic metabolic products of DDT.

SOURCES: Office of Technology Assessment, [illegible] Drug Administration, [illegible] Center for Food Safety and Applied Nutrition, [illegible] (Washington, DC: [illegible] for PCBs: 21 CFR Subpart B, Section 109.30.

*The intent of such inspections (e.g., the number of individual substances to the [illegible]) was [illegible]. Testing is performed routinely for fecal coliform bacteria, for example, but not for viruses.

outbreaks of serious shellfish-borne, bacterial disease, including epidemics of typhoid and paratyphoid fever, they cause major economic impacts. In Washington, 21 percent of the shellfish-growing areas are closed and another 11 percent are only provisionally open because of bacterial contamination. Moreover, contamination appears to be increasing: six previously pristine areas in Puget Sound have been closed in the last 3 years (463). Fishing in many other areas has been restricted periodically due to sewage contamination (e. g., Boston Harbor, New York Harbor, and portions of Narragansett Bay, the Delaware River estuary, Chesapeake Bay, Mobile Bay, and San Francisco Bay).

Overall, the incidence of shellfish-borne disease is not decreasing in the United States and may be increasing (197). This trend largely involves increases in the number of outbreaks of *viral* disease

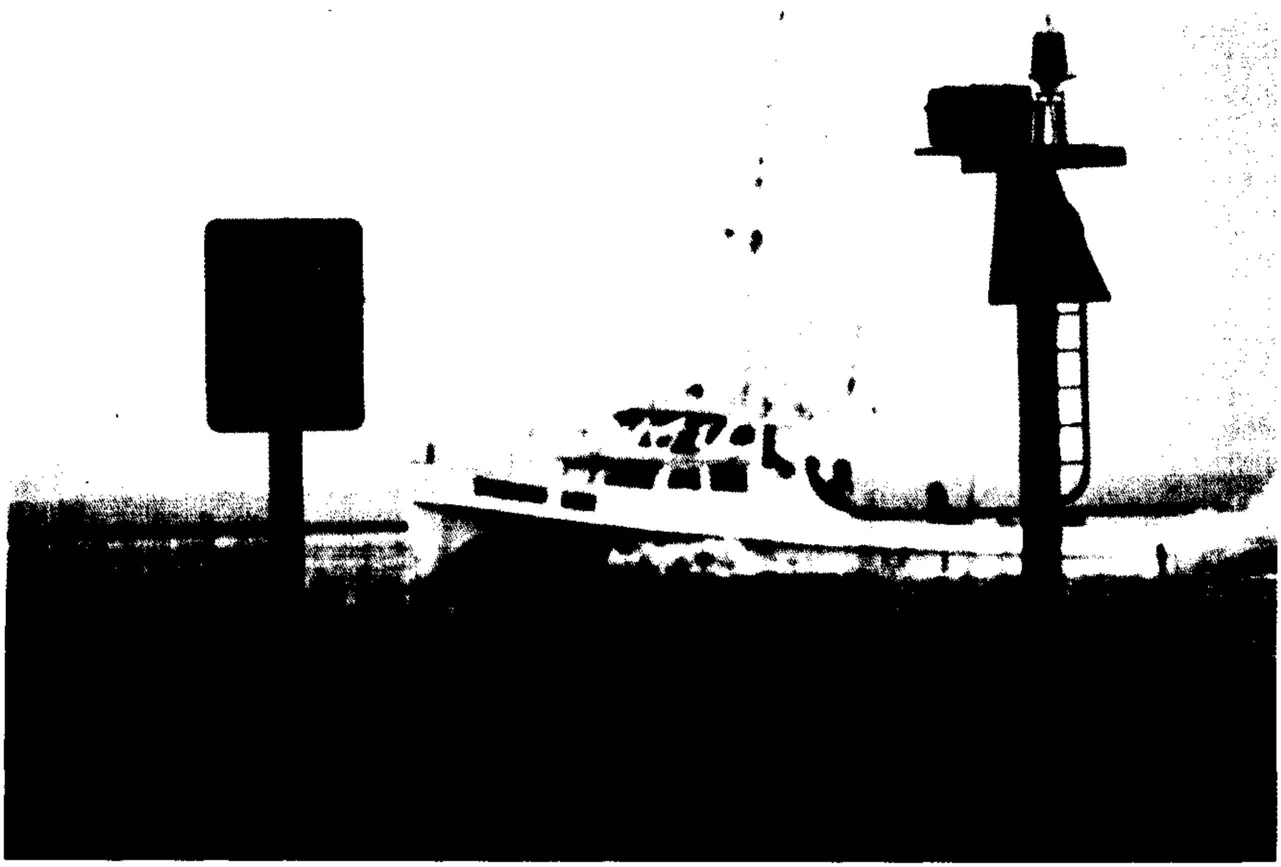

Photo credit. Northeast Technical Services *Administration, U S Food and Drug Administration*

Contamination of shellfish is a significant problem nationwide. The problem is growing, particularly in rapidly developing areas such as coastal portions of the Gulf of Mexico and southern Atlantic States.

(e. g., 80,367). For example, in the State of New York in 1982 alone, consumption of contaminated shellfish was identified as the cause of 103 different reported outbreaks of viral gastroenteritis involving over 1,000 people (367). Smaller outbreaks of more serious bacterial diseases also have been reported. In a series of apparently related cases stretching back over the last 14 years, several dozen people contracted cholera after consuming shellfish harvested from coastal marshlands in southwestern Louisiana (81,82). These represent the first indigenous outbreaks of cholera in the United States since 1911 (78).[12]

[12] While the bacteria responsible for cholera are natural constituents of marine waters, their survival in this case is thought to be enhanced through a cycle of, 1) sewage contamination of marsh water, 2) shellfish contamination, 3) human infection from consumption of shellfish (in some cases inadequately cooked), and 4) human fecal excretion into sewage (35). The presence of the infective agent in marsh water, shellfish, and sewage from several towns in the area has been documented repeatedly (35,82).

Water-Borne Disease

While the implementation of water quality guidelines and sewage treatment requirements has substantially reduced the outbreaks of serious human diseases attributable to direct contact with polluted waters, bathing in sewage-impacted waters is responsible for relatively high rates of gastrointestinal illness in the United States. In fact, the number of outbreaks of water-borne disease, particularly nonbacterial diseases such as viral gastroenteritis and hepatitis, has been steadily increasing in recent decades (79, 197).[13] Recent epidemiologic evidence has shown that the incidence of gastrointestinal illness is significantly elevated in people

[13] Much of this type of illness goes unreported because of its relatively benign nature and the underreporting significantly hinders accurate measurement of true incidence. Data on the incidence of water-borne disease do not generally distinguish between fresh and marine waters.

swimming at several heavily used New York City beaches (63,641) and in Lake Pontchartrain in New Orleans, Louisiana (285).[14]

Epidemics of serious bacterial disease, while rare, have been caused by swimming in sewage-contaminated water. For example, in 1974 an outbreak of shigellosis was traced to swimming in a stretch of the Mississippi River downstream of a secondary treatment plant. Fecal coliform counts in the river were almost 90 times higher than the Federal standard (489). Similarly, outbreaks of typhoid fever in Australia and Egypt have been caused by swimming in sewage-contaminated marine waters (205).

Scuba diving in contaminated marine waters can also lead to increased incidence of waterborne disease (1 13,192,205,435). These diseases include dermatitis, wound infections, and other skin-related ailments, as well as enteric illness. Under-reporting of such diseases is judged to be considerable (205).

Shortcomings of Current Microbiological Standards

Many observers have raised concerns about the adequacy of current efforts to control and monitor microbiological contamination of marine waters and resources. Three major shortcomings need to be addressed:

1. current standards designed to protect humans against microbiological agents in marine waters or seafood may be too lenient,
2. monitoring protocols are inadequate to detect periodic violation of the standards, and
3. standards based on use of fecal coliform indicators do not adequately measure pathogen survival.

Current techniques used to measure marine water quality are probably significantly underestimating the true number of viable pathogens that are entering the marine environment, for at least four reasons (205). *First,* coliform bacteria, which have been used to indicate sewage contamination of water for 75 years, generally are not pathogenic, and do not survive as well as other pathogenic bacteria or viruses (481). In fact, studies show that gastroenteritis associated with swimming (at least in marine waters) is better correlated with enterococcal bacteria than with coliforms (63,285,641). In addition, outbreaks of gastroenteritis have been associated with shellfish harvested from waters that were deemed acceptable using traditional indicators (451 ,700).15

Second, existing standards use bacteria as indicators of contamination, while *viruses* appear to be the major cause of diseases resulting from exposure through both direct (swimming, diving) and indirect (seafood consumption) pathways (197). *Third,* current standards are based solely on water quality, while levels in sediments and shellfish are neither regulated nor routinely monitored. Yet sediments are probably an equal or more likely source of pathogens in shellfish (197).

Finally, increasing evidence suggests that bacteria (including certain human pathogens) introduced into the marine environment do not die off as rapidly as once believed, but remain viable for extended periods of time (e. g., months to years). These pathogens cannot be cultured in the laboratory and their presence cannot be detected using traditional tests, but they can be reactivated within a host organism (106,206). Thus, the apparent lack of human pathogens in the open ocean, especially at or near past sewage sludge disposal sites, may simply reflect our inability to detect these apparently viable, non-culturable pathogens (205).

The public health significance of the viable-but-not-culturable phenomenon is far from clear, however, and remains controversial. No definitive link has been established between the survival of bacterial pathogens through this mechanism and the occurrence of human disease. Moreover, because most disease related to exposure to marine waters or fish is caused by viruses rather than bacteria, the role that pathogenic bacteria in marine envi-

[14]These studies are significant because they demonstrate that not only can the presence of sewage-derived material in the marine environment result in human disease, but also that disease rates that are significant from a public health perspective can be difficult or impossible to discern in the absence of carefully performed, thorough (and expensive), epidemiologic studies.

[15]EPA has recently adopted enterococci as an indicator of microbiological water quality for marine *recreational* waters (664). It is not yet clear what influence adoption of the new standard and indicator will have on consideration of alternative indicators and standards for monitoring of the quality of shellfish and shellfish-harvesting waters (205).

ronments play in human disease is probably of secondary importance.

The Effect of Treatment on Pathogenic Microorganisms

Sewage Treatment

Wastewater treatment results in the partitioning of waste constituents into sewage effluent and sludge. Wastewater treatment and subsequent sludge treatment processes can in many cases significantly reduce the numbers of some types of sewage microorganisms. However, the actual extent of reduction varies considerably from operation to operation, and among classes of microorganisms. A full discussion of this topic is included in chapter 9.

Chemical Disinfection of Wastewater Effluents

In most instances, bacteriological water quality standards for recreational and shellfish-growing waters are met by chemically disinfecting sewage effluent prior to discharge. Chlorination traditionally has been viewed as an effective and economical means to reduce levels of microorganisms in effluent. However, concerns have been raised that chlorinated hydrocarbons (e. g., chloroform) formed as byproducts of chlorination pose significant risks to organisms in the immediate vicinity of treatment plant discharges. One alternative to chlorination is the use of long deep-ocean outfalls such as those employed in southern California. These achieve water quality standards through dilution.

The effectiveness of either approach in reducing pathogen exposure risks is questionable, however, given the traditional use of coliforms as the standard indicator species and the growing evidence that bacteria discharged in sewage effluent may persist in marine waters in a viable but nonculturable form. Substantial data indicate that:

1. chlorination is more effective against coliforms than against pathogenic viruses or even numerous pathogenic bacteria;
2. pathogenic viruses and bacteria can survive significantly longer in the marine environment than can coliforms; and
3. chlorination may only temporarily inactivate, rather than destroy, microorganisms present in effluent (205,297).

These findings suggest that the routine discharge of sewage effluent and the dumping of sewage sludge into estuaries, coastal waters, and the open ocean may be introducing large numbers of viable microorganisms, including pathogens, and that their densities in both the water and sediments may be increasing. Further study of the public health consequences of these practices is needed, particularly in light of the increasing incidence of shellfish- and water-borne disease.

Land Application of Sewage Sludge

Because sewage sludge is applied to land as fertilizer and for reclamation purposes, the survival and availability of pathogens in the sludge is of considerable public health significance. Viruses, bacteria, and parasites can survive in soil for many days or months depending on soil temperature, pH, clay content, cation exchange capacity, surface area, moisture content, and organic content. Viable pathogens have been found, for example, in surface runoff from sludge-amended fields. However, there are no documented cases of human disease resulting from land application of treated sewage sludge, although untreated sewage-derived wastes have often been implicated in disease outbreaks (60,205,379). Land application and landfilling of treated sewage sludge appear to pose less potential health risks to humans than disposal in freshwater or estuarine environments.

Deputation of Shellfish

Some countries (e. g., Japan) allow or even encourage the culturing and harvesting of shellfish in sewage-contaminated water to take advantage of the nutritive content of such wastes. Prior to marketing, these shellfish are depurated (i. e., placed in clean water for several days) to allow the shellfish to purge themselves of pathogens. This practice is controversial, however, because evidence indicates that deputation does not eliminate all pathogens, especially small bacteria or viruses such as the Hepatitis A 'virus (186,209,298,368,523). These and other studies suggest that further systematic study of the health risks associated with various forms of deputation should be conducted prior to its use as an accepted means of decontaminating shellfish (205),