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Diseases Transmitted by Foods Contaminated by Wastewater

FRANK L. BRYAN

Bureau of Training, Center for Disease Control, Public Health Service, U.S. Department of Health, Education, and Welfare, Atlanta, Georgia 30333

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ABSTRACT

A historical and world-wide review of medical and engineering literature discloses that typhoid fever, infectious hepatitis, fascioliasis, and cholera are the diseases that have been most frequently transmitted by foods contaminated by sewage or irrigation water in agricultural or aquacultural practices. Wastewater-contaminated shellfish have resulted in 28 outbreaks of illness, watercress in 10, fish in three, and shrimp in one. Vegetables contaminated by night soil or raw or partially treated sewage were reported as vehicles in 21 outbreaks. Fruits were considered as vehicles in four outbreaks. For such outbreaks to occur, a complicated chain of events must occur for agents originally present in wastewater to survive natural destructive forces and wastewater-treatment processes or to multiply so that there are sufficient numbers to cause illness.

In a world of limited resources and expanding human populations, an ample and safe food is vital for populations to thrive. New food sources and improvements in agricultural and aquacultural methods must be investigated and utilized; wastes generated by increasing concentrations of people must be disposed of adequately. Recycling wastewater for watering and nourishing food crops or for growing fish contributes to both food production and waste disposal. But when wastewater is used to irrigate crops or to provide water in aquaculture, appropriate precautions must be taken to prevent the diseases that might otherwise be transmitted by wastewater-contaminated foods.

Foods can become contaminated during production either on farms or in watercourses, during processing in food processing plants, and during preparation in food service establishments and homes. The point at which contamination occurs will depend on the natural sources of a pathogen and on the opportunities for transfer at each stage of the food chain. Factors that contribute to reported foodborne disease outbreaks are reviewed (*24*).

Many of the pathogenic organisms that infect man reach him by being conveyed by more than one vehicle. For example, eggs of some parasitic organisms can appear in feces of infected persons, reach water in which they hatch into a form that infects a vector (as a snail), and, after a period of development metamorphize into a free-swimming form which penetrates tissues of fish or water vegetables. Diseases caused by such parasites and features of their transmission are listed in Table 1. Few

TABLE 1. *Parasitic diseases maintained by the cycle: Human feces to water or soil; water or soil to food; food for human consumption*

Agent	Intermediate vehicle	Intermediate host	Food
Clonorchis sinensis	fresh water	snail	fish
Diphyllobothrium latum	fresh water	copepods	fish
Echinostoma ilocanum	fresh water	snail	snails, clams, limpets, fish, tadpoles
Fasciola hepatica	fresh water	snail	watercress
F. gigantica			water vegetables
Fasciolopsis buski	fresh water	snail	water vegetables
Opisthorchis felineus	fresh water	snail	fish
Paragonimus westermani	fresh water	snail	crabs, crayfish
Taenia saginata	soil (grass)		beef
Taenia solium	soil (grass)		pork

of these parasites are found in the United States, but they are prevalent in other regions of the world. Other parasites, such as those that cause hookworm infection, schistosomiasis, and leptospirosis, penetrate human skin in their infective stage and may be acquired by agricultural or aquacultural workers who work in wastewater-contaminated fields or ponds (*180*).

Most of organisms that are conveyed by wastewater-contaminated foods have less complicated transmission cycles. The organisms that have potential of transmission by such a route, and the diseases they cause, are listed in Table 2.

The following circumstances must occur for persons who ingest wastewater-contaminated foods to become ill. (*a*) The infectious agent must be present in citizens of a community or in animals on farms, or toxic agents must be used for industrial or agricultural purposes; and wastes from these sources must reach sewerage or

TABLE 2. *Diseases and causative agents transmissible by food that has been contaminated by wastwater or by soil that contains fecal material*

Disease	Agent
	BACTERIA[a]
Arizona infection	*Arizona hinshawii*
Bacillus cereus gastroenteritis	*Bacillus cereus*
Cholera[b]	*Vibrio cholerae*
Clostridium perfringens gastroenteritis	*Clostridium perfringens*
Enteropathogenic *Escherichia coli* infection	*Escherichia coli* (certain toxinogenic and invasive types)
Paratyphoid fever[b]	*Salmonella paratyphi* A
	Salmonella paratyphi B
	Salmonella paratyphi C
	Salmonella sendai
Salmonellosis[b]	*Salmonella* (over 1,500 serotypes)
Shigellosis[b]	*Shigella sonnei*
	Shigella flexneri
	Shigella dysenteriae
	Shigella boydii
Typhoid fever[b]	*Salmonella typhi*
Yersinia gastroenteritis	*Yersinia enterocolitica*
	Yersinia pseudotuberculosis
	VIRUSES
Adenovirus infection	Adenoviruses
Coxsackie infection	Coxsackie viruses
ECHO virus infection	ECHO viruses
Poliomyelitis	Polioviruses
Reovirus infection	Reoviruses
Viral hepatitis[b]	Hepatitis virus A
Winter vomiting disease	Norwalk agent
	HELMINTHS
Ascariasis[b]	*Ascaris lumbricoides*
Trichiniasis	*Trichuris trichiura*
	PROTOZOA
Amebiasis[b]	*Entamoeba histolytica*
Balantidiasis	*Balantidium coli*
Coccidiosis (Isospora infection)	*Isospora belli, I. hominis*
Dientamoeba infection	*Dientamoeba fragilis*
Giardiasis	*Giardia lamblia*

[a]Other enteric bacteria which could conceivably be transmitted by foods but proof is inconclusive: *Streptococcus faecalis, S. faecium, Proteus* spp., *Providencia* spp., *Klebsiella* spp., *Citrobacter freundii, Enterobacter* spp., *Edwardsiella tarda, Aeromonas* spp., *Plesiomonas shigelloides, Pseudomonas aeruginosa*

[b]Reported outbreaks, see Table 8.

drainage systems. (*b*) The agents must survive and pass through all wastewater treatment processes to which they are exposed. (*c*) The waste-treatment effluent or water course receiving the effluent must be used as irrigation water for crops or as a growing environment for fish or watercrops or for washing or freshening harvested foods. Thus, the agents must survive in the receiving watercourse. (*d*) The agents must survive in the soil in which irrigated foods are grown. (*e*) The agents must contaminate a food product. (*f*) Then one of the following events must occur: (*i*) The agents must be present on the contaminated food in sufficient numbers to survive the remainder of the growing period, storage, and preparation and still cause illness. (*ii*) Bacteria on foods in insufficient numbers to cause illness must multiply and reach numbers that are necessary to cause illness. (*iii*) Bacteria, and perhaps other organisms, enter food preparation areas on raw foods, where they may be transferred to workers' hands or to equipment surfaces which if inadequately washed will then contaminate other foods that they subsequently touch. (*g*) Sufficient quantities of the contaminated food that contain enough of the agent to exceed a person's susceptibility threshold must be ingested. Ingestion of foods contaminated to this level may result in sporadic cases of illness as well as epidemics. When insufficient numbers of pathogens to cause illness are ingested, the infected individuals may become carriers and subsequently contaminate other foods that they touch. Each step of this chain of events necessary for wastewater to contribute to foodborne outbreaks of human disease is reviewed based on information from engineering and medical literature.

PATHOGENS IN SEWAGE

Numerous investigators have isolated pathogens from sewage. These investigations have been reviewed by Rudolfs et al. (*158, 159*), Greenberg and Dean (*74*), Kollins (*99*), and Grabow (*72*). Animal wastes contain many of the same pathogens as well as other pathogens.

SURVIVAL IN WASTE–TREATMENT PROCESSES

Enteric pathogens survive some stages, and sometimes the entire process of wastewater treatment. Table 3 highlights the results of some typical investigations of the effect of various wastewater-treatment processes in removing or killing pathogens. Primary sedimentation usually removes less than 50% of coliform and pathogenic bacteria from sewage; it is relatively ineffective in removing viruses and protozoa. Activated sludge or trickling filter processes followed by secondary sedimentation usually remove over 90% of coliform or pathogenic bacteria remaining after primary sedimentation. Viruses can be significantly reduced by activated sludge but not by trickling filter processes. Sand filtration is required to remove amoebic cysts and *Ascaris* eggs. Anaerobic digestion reduces 90% of pathogenic bacteria from sludge but is less effective for destruction of *Ascaris* eggs. Hepatitis viruses, *Entamoeba histolytica* cysts, and tapeworm eggs withstand the chlorination treatment generally applied to waste-treatment effluent. Thus, many waste-treatment processes remove or kill 90% or more of the pathogens that are present in influent sewage, but some still remain in the effluent. If a million pathogens, for example, are present in influent sewage before exposure to processes which remove 90% of them, 100,000 survive; in the event of 99% destruction, 10,000 survive. Kampelmacher and van Noorle Janssen (*92*) fount that 10^{10} salmonellae entered a trickling filter secondary treatment plant each hour and that 10^9 left the plant in the effluent each hour.

SURVIVAL IN RECEIVING WATERCOURSES AND USE OF WASTEWATER FOR IRRIGATION

Those organisms that survive wastewater treatment must also survive in receiving waters. Such survival has been reviewed by Rudolfs (*158, 159*), Dunlop et al (*49*), Clarke et al. (*31*), Kollins (*19*), and Grabow (*72*). Factors influencing survival in water include temperature, amount of light, flow rate, presence of oxygen, pH,

TABLE 3. *Survival of pathogens during various stages of wastewater treatment*

Pathogen	Process: Settling	Activated sludge	Trickling filtration	Anaerobic digestion	Sand filtration	Drying	Stabilization pond	Disinfection	Reference
Salmonella typhi		++							(26)
		++							(138)
		++							(156)
		++	++						(73)
	+++			+		−			(127)
							−		(68)
				+		+			(166)
				++					(123)
							+/−		(122)
Salmonella	+	+							(19)
							+		(34)
								−	(22)
						+			(104)
paratyphi		++							(26)
				+		+			(166)
			++						(117)
utrecht	+++		+++						(92)
Shigella		++							(26)
flexneri							−		(34)
Vibrio		−							(39)
cholerae		++							(26)
Streptococcus			++		++				(2)
faecalis	++++		+++					++	(35)
Enteroviruses	+	+							(20)
	+	+							(32)
		++						+	(108)
Polioviruses		−							(28)
	+								(93)
	+		+			+			(94)
		+							(109)
								−	(178)
	++++	−	+	−				+	(95)
	+++	++							(29)
	++++	+++							(96)
					−(++)				(153)
	++++	++							(30)
			+++						(33)
							+		(112)
Coxsackie	++++		+++					+/−	(66)
viruses			+						(33)
								+++	(67)
		+							(109)
					+			+	(29)
	++++	−	+	−				+	(95)
	++++	++++	++++		++		+		(86)
			+++						(33)
ECHO		+							(109)
viruses			+++						(33)
Hepatitis virus A								+	(131)
Entamoeba histolytica	+							++++	(71)
	++++	++++	+++	−	−	+		++++	(40)
	+	+	+	+	−				(75)
						+			(104)
coli	++							++	(175)
Giardia lamblia						+			(104)
Ascaris	+	+	+++	+	−	+			(40)
lumbri-	+	+	+	+	−				(75)
coides	−			+					(147)
eggs	+++							+++	(175)
	+++	++	++	++++					(17)
Trichuris						+			(104)
trichiura	+++	++							(17)
Tapeworm eggs			++++	++				++++	(172)
Taenia	+	+	+	+	−				(75)
saginata	+++	++++	+++	++++	−				(132)

− destruction; + survival; ++ over 90% removal; +++ over 50% removal; ++++ less than 50% removal dilution, amount of dissolved material, and types of organisms in the water.

Irrigation water may be sprayed over crops, flow through channels in fields and seep to roots, or be flooded over the field. The numbers of pathogens applied to soil during irrigation can be of such magnitude that outbreaks can result. During an epidemiologic investigation, Renteln and Hinman (*150*) found that sewage plant effluent used to irrigate a field was channeled by gopher holes to a well pit and entered a community water supply through a defective well casing. Aerosols will be produced during spraying and pathogens trapped in the aerosols may be conveyed to locations other than the irrigated fields by wind and air currents.

SURVIVAL OF PATHOGENS IN SOIL

After wastewater or receiving water is used for irrigation, enteric pathogens must survive long enough to contaminate crops. Helminths not only survive in soil but must stay in soil for a period of several days to develop into an infective stage. Survival times for many enteric pathogens in soil are reviewed in Table 4. Factors that effect resistance include number and type of organism, type of soil (structure, moisture content, pH, amount of organic matter) temperature, amount of rainfall, amount of sunlight, protection provided by foilage, and competitive microbial flora. The range of survival times suggests that pathogens introduced into a field by irrigation with wastewater would, despite considerable reduction in numbers, survive in the soil until harvest under some agricultural conditions. Pathogens in soil are more likely to contaminate foods if the soil is kept moist by intermittent application of irrigation water. Also, continuous application of wastewater to soil results in accumulation of pathogens in soil. Soil filters microorganisms and they often concentrate near areas where plants grow.

TABLE 4. *Survival of enteric pathogens in soil*

Pathogen	Type soil	Survival (in days)	Reference
Salmonella typhi	moist sand	<12	(*62*)
	peat	<13	
	damp soil	35-74	
	soil surface (sunlight)	5-22	
	soil	70-80	(*110*)
	soil	35	(*41*)
	garden soil (in open)	32-58	(*124*)
	sandy soil	29-36	
	garden soil (hot house)	49-74	
	sandy soil (hot house)	53	
	moist neutral soil	70	(*97*)
	moist arid soil	<10-30	
	dry soil	<14	
	sand	<5	(*13*)
	muck	12	
	clay loam	12	
	sandy loam	5	
	adobe	21-105	(*113*)
	adobe-peat	28-100	
	loam	21-120	
	sand	2-15	
	peat	1-2	
	loam sand	14-60	
Salmonella	soil and pasture	>200	(*177*)
	soil (raw sewage)	46	(*145*)
	soil	46-70	(*15*)
	sandy soil	35-84	(*151*)
	soil and pasture	>280	(*111*)
	soil	147-259	(*168*)
Streptococcus faecalis	sandy loam	28-77	(*113*)
	sand	33-35	
	loam	26-63	
	clay loam	33-49	
	muck	40-77	
Endamoeba histolytica	moist soil	6-8	(*14*)
Ascaris ova	irrigated soil	730-1035	(*77*)
	soil	2190	(*100*)

CONTAMINATION OF FOODS

Foods become contaminated from water during irrigation (flooding, spraying, or seepage), from soil when the plant grows, when vegetables or fruits fall on the ground, and when the crop is harvested. They also are contaminated by dust blowing over the crops or from workers, birds, and insects that convey organisms from irrigation water or soil to the foods. Organisms contaminating foods in one of these ways remain on the food surface until they succumb to dessication, exposure to sunlight, starvation, or action of other organisms. They do not penetrate into the vegetables or fruits unless their skin is broken. Survival times of many enteric pathogens on foods are reviewed in Table 5. These times suggest ample opportunity for crops that become contaminated during irrigation or during growth to remain contaminated until harvest. Shellfish and watercress trap and accumulate enteric pathogens; thus, they become particularly hazardous of grown in sewage-contaminated water. Foods sprayed with wastewater a short time before harvest could harbor pathogens on their surfaces.

Pathogens are infrequently isolated from foods in fields or after harvesting. When pathogens are found,

TABLE 5. *Survival of enteric pathogens on foods*

Pathogen	Vegetable	Survival (in days)	Reference
Salmonella typhi	vegetables (leaves and stems)	10-31	(*41*)
	radishes	28-53	(*124*)
	lettuce	18-21	
Salmonella	vegetables	40	(*100*)
	vegetables	28	(*143*)
	beet leaves	21	
	tomatoes (laboratory)	20	(*160*)
	tomatoes (field)	3	
	soil and potatoes	>40	(*129*)
	carrots	>10	
	cabbage and goose-berries	> 5	
	tomatoes	3	(*58*)
Shigella	clams and shrimp	>60	(*167*)
sonnei and	oysters	>40	
S. flexneri	tomato (surface)	2	(*89*)
S. sonnei	tomato (tissue)	10	
	apple (skin)	8	
Vibrio cholerae	vegetables	5	(*70*)
	dates	<1-3	
	shellfish	20-45	(*142*)
	vegetables	7	(*59*)
	vegetables (refrigerated)	<14	
Entamoeba histolytica	lettuce and tomatoes	< 3	(*161*)
Ascaris ova	lettuce and tomatoes	27-35	(*162*)

they are found in low percentage of samples and usually for only a short time after irrigation. Studies in which isolations were made are summarized in Table 6.

TABLE 6. *Recovery of pathogens from foods contaminated by wastewater*

Pathogen	Food	Source of contamination	Reference
Salmonella typhi	leaf tips	contaminated soil	(*41*)
	radishes	contaminated soil	(*124*)
	lettuce	contaminated soil	
Salmonella (other types)	celery	irrigation water	(*50*)
	vegetables	irrigation water	(*48*)
	fish	river water	(*114*)
	green onions	irrigation water	(*65*)
Salmonella, Shigella other bacterial pathogens (serologic evidence)	white perch	river water near heavily populated areas	(*88*)
Enteropathogenic *Escherichia coli*	fish	river water	(*69*)
Enteroviruses (Polio, ECHO, Reo, Coxsackie)	vegetables	irrigation water	(*10*)
	oysters	sewage-contaminated sea water	(*125*)
Ascaris ova	lettuce	irrigation water	(*175*)
	cabbage	irrigation water	
Helminth ova	vegetables	irrigation water	(*173*)
	cucumbers	irrigation water	
	tomatoes	irrigation water	
	carrots	irrigation water	

SURVIVAL, CROSS-CONTAMINATION, AND MULTIPLICATION

Foodborne disease organisms must survive processing and preparation steps and bacteria usually have to multiply to reach infective levels. If wastewater-contaminated fruits, vegetables, or seafoods are cooked so that the contaminated portions reach 165 F (or even lower temperatures for sufficient time), vegetative bacteria (but not spores), protozoa, helminthic eggs, and most viruses will be killed. All foods, however, are not cooked before serving, and the temperatures reached during cooking may be too low to kill pathogens.

Contaminated raw foods bring pathogens into food preparation environments. These organisms are killed in foods that are thoroughly cooked, but before cooking they can contaminate the hands of any worker who touches them, or they can contaminate equipment that they contact. Such cross-contamination is commonly reported in outbreaks of salmonellosis; the initial source is usually raw meat or poultry. Some food service workers and homemakers are aware of this danger, but they are unaware that wastewater-contaminated vegetables present the same hazard. Citizens in the United States assume that the fruits, vegetables, and shellfish they eat are free from fecal contamination. But this is true only if wastewater has not contaminated crops or the waters in which shellfish grow.

Contaminated foods which are to be eaten raw or used as a raw ingredient in a salad can support growth of foodborne disease bacteria under the following set of conditions: foods must contain sufficient moisture and essential nutrients to support bacterial growth; foods must be held within a temperature range that permits the contaminating bacteria to multiply, usually near the organism's optimal temperature for growth; and foods must be held at such temperatures for sufficient time for enough organisms or toxins to be produced to cause illness in those who ingest the contaminated food.

NUMBERS OF PATHOGENS REQUIRED TO CAUSE ILLNESS

Ingestion of contaminated food does not always result in illness. The pathogens must be swallowed in sufficient quantity to exceed a person's threshold of susceptibility if illness is to result. Human volunteer feeding studies have indicated susceptibility threshold levels of various enteric pathogens. Table 7 reviews such studies. Conceivably, wastewater-contaminated food could harbor 10 *Shigella dysenteriae* 1, 180 *Shigella flexneri* 2a, or 1,000 *Vibrio cholerae* biotype ogawa (numbers found to cause illness in adult volunteers) when they reach the consumer. Thus, ingestion of foods contaminated at these levels could result in illness. Such foods could also convey 1 *Entamoeba coli*, 10 *Giardia lamblia*, and 1,000 *V. cholerae* biotype inaba, which if ingested could result in infection and carrier status. Ten thousand *Salmonella typhi* and *V. cholerae* biotype inaba could, conceivably, be present on foods recently fertilized with night soil, human manure, or raw sewage; and ingestion of this amount of these pathogens could cause illness. Certain waterborne outbreaks of these diseases and other diseases, such as salmonellosis, suggest that even lower levels of organisms than those indicated by volunteer feeding studies cause illness. As few as 15,000 *Salmonella cubana* caused death in infants who were given contaminated carmine dye for diagnostic purposes (*103*). All volunteer studies cited were conducted on health adults. Infants, elderly persons, malnourished persons, and persons with concomitant illness would be more susceptible—perhaps a one or more log reduction in dosage could result in illness of such persons. Most of the other organisms in which human feeding tests have been done, as well as some of the organisms just cited, usually require time for mulitplication before the large numbers (100,000 or more) necessary to cause illness would be generated. Thus, it would be unlikely for an infective dose of salmonellae to be on lettuce or other raw vegetables, but it is possible for the same foods to contain an infective dose of shigellae, *Ascaris*, or *E. histolytica*. One saving feature is that shigellae and *E. histolytica* do not survive long in the competitive environment which occurs in wastewater, soil, or foods. Salmonellae and many of the other bacteria which have been mentioned would become problems if contaminated foods were allowed to stand at room temperatures or refrigerated in large masses.

OUTBREAKS

On some occasions all circumstances described have occurred and outbreaks of human illness have resulted.

TABLE 7. *Clinical response of adult humans to varyious challenge doses of enteric pathogens*

Organism (strain)	Challenge dose 10^1	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9	10^{10}	10^{11}	Reference
Shigella dysenteriae												
(1) (A-1)		+		++								105)
(1) (M 131)	+	++	+++	++++								(105)
Shigella flexneri (w)									+++			164)
(2a)				+	+++	++++	+++	++++				(51]
(2a)		+	+++	+++	+++							(54)
Vibrio cholerae												
inaba 569B (unbuffered)				—		—	—	++	++	—	++	(84)
inaba 569B (+$NaHCO_3$)	—		(+)	+++	+++[a]	+++[a]		++[a]				(84)
ogawa (+$NaHCO_3$)			++			++[a]						(84)
Salmonella typhi												
(Quailes) vi			—		++		++	++++	++++			(82)
(Zermat) vi				+++								(82)
(Ty2V) vi						++						(82)
(O-901)								++				(82)
(Ty2W)								+				(82)
(Quailes)					+		++		++++			(83)
(Quailes)					++							(52)
Salmonella newport					+	++						(120)
Salmonella bareilly					+	++						(120)
Salmonella anatum												
(I)				—	+							(118)
(II)				—	—	—	+					(118)
(III)				—	—	++	+	+				(118)
*						++	+	+				(119)
Salmonella meleagridis (I)				—	—	—	++					(118)
(II)						—	++					(118)
(III)					—	+	++					(118)
*							+++	+++				(119)
Salmonella derby					—	—	++					(120)
Salmonella pullorum (I)				—	—	—	—	—	—	++++		(121)
(II)				—	—	—	—	—	++++			(121)
(III)				—	—	—	—	—	++++			(121)
(IV)				—	—	—	—	—	++			(121)
Escherichia coli												
(O111:B4)						+++		+++	+++			(60)
(O55:B4)								+++	+++	++++		(91)
(O6:H16)								++		+++		(53)
(O124:K72:H-)								+		(+)		(53)
(O143:K?H-)				(+)		(+)		+++				(53)
(O144:K?:H-)				—		+		+++				(53)
(O148:H28)								+		++++		(53)
Streptococcus faecalis var. *liquefaciens*								—	+	++		(162)
Clostridium perfringens type A (Heat-resistant)								++	+++			(43)
Clostridium perfringens type A (Heat sensitive)									++++			(80)
Entamoeba coli	(++)	(++)	—	(++++)								(148)
Giardia lamblia	(++++)	(++)		(++++)	(++++)	(++++)						(149)
Norwalk agent[b]												
**1 ++												
2 +++												
3 +												(46)
Hepatitis virus A[b] +++												(81)
(fecal filtrates) ++												(130)

— = 0, + = 1-25, ++ = 26-50, +++ = 51-75, ++++ = 76-100 % of volunteers developing illness
*Refeeding trials of volunteers who months before became infected by the same strain
**1, 2, 3 refers to serial passages of stool filtrates
(+) Infections without illness
[a]Cholera-like diarrhea
[b]Fecal filtrates

TABLE 8. *Outbreaks associated with foods contaminated by sewage or wastewater*

Disease	Source of contamination	Food	Reference
Typhoid fever	Sewage-polluted waters	oysters	*(5)*
Typhoid fever	Sewage sludge fertilizer and irrigation	celery	*(128)*
Typhoid fever	Sewage-contaminated watercress beds	watercress	*(176)*
Typhoid fever	Sewage-polluted water	shellfish	*(133)*
Typhoid fever	Sewage-polluted water[a]	oysters, raw vegetables and fruits	*(106)*
Typhoid fever	Human manure	rhubarb	*(141)*
Typhoid fever	Privy-polluted water-cress beds	watercress	*(139)*
Typhoid fever	Sewage irrigation	vegetables, blackberries	*(7)*
Typhoid fever	Sewage irrigation	raw vegetables	*(6)*
Typhoid fever	Sewage-polluted water	oysters	*(25)*
Typhoid fever	Sewage-polluted water[a]	oysters	*(107)*
Typhoid fever	Sewage-polluted water[a]	oysters	*(107)*
Typhoid fever, gastroenteritis	Fecal-polluted (privy and boats) water	oysters	*(146)*
Amebiasis	Sewage irrigation	vegetables	*(4)*
Taeniasis	Sewage irrigation	beef	*(137)*
Typhoid fever	Sewage-polluted wastes (privies and raw sewage)	oysters	*(134)*
Typhoid fever, paratyphoid fever	Secondary sewage treatment (activated sludge)[b] plant effluent irrigation and wash water	vegetables	*(45)*
Typhoid fever	Sewage	clams	*(79)*
Shigellosis	Irrigation water (Primary treatment plant effluent)[c]	cabbage	*(64)*
Amebiasis	Night soil	vegetables	*(1)*
Typhoid fever	Sewage-polluted water-cress beds	watercress	*(42)*
Ascariasis	Sewage spray irrigation	vegetables	*(12)*
Typhoid fever	Sewage manure	vegetables	*(77)*
Typhoid fever	Night soil	vegetables	*(174)*
Ascariasis	Night soil	vegetables	*(3)*
Tyhpoid fever	Sewage irrigation	apples	*(154)*
Salmonellosis	Sewage irrigation and sludge	vegetables	*(101)*
Typhoid fever	Human fecal material as manure	endive	*(78)*
Typhoid fever	Human fecal material as manure	raw salad	*(78)*
Typhoid fever	Night soil	vegetables	*(100)*
Ascariasis	Night soil	vegetables	*(100)*
Ascariasis	Night soil	vegetables	*(126)*
Hookworm infection	Sewage farming	vegetables	*(140)*
Viral hepatitis	Sewage-polluted water	oysters	*(155)*
Typhoid fever	Sewage[a]	vegetables, fruits, shellfish	*(37)*
Diphyllobothriasis	Sewage-polluted water	fish	*(165)*
Fascioliasis	Animal feces[a]	watercress	*(57)*
Viral hepatitis	Sewage-polluted water by primary treatment effluent, raw sewage, and septic tank discharges[c]	clams	*(152)*
Typhoid fever	Sewage-polluted water[a]	oysters	*(21)*
Viral hepatitis	Sewage-polluted water (overtaxed treatment plant effluents)	clams	*(49)*
Viral hepatitis	Sewage-polluted water (treatment plant by-passed)	oysters	*(115)*
Viral hepatitis	Sewage-polluted water	oysters	*(169)*
Viral hepatitis	Sewage-polluted water	oysters	*(170)*
Fascioliasis	Sewage-polluted water[a]	watercress	*(135)*
Cholera	Sewage-polluted water	shrimp	*(90)*
Fascioliasis	Sewage-polluted water[a]	watercress	*(38)*
Salmonellosis	Dead animal in polluted water from which cows drank	raw milk	*(61)*
Viral hepatitis	Sewage-polluted water	oysters	*(170)*
Viral hepatitis	Sewage-polluted water	clams	*(170)*
Taeniasis	Human feces contaminated trench silo	rare beef	*(27)* *(136)*
Minamata disease (organic mercury poisoning)	Industrial waste	fish, shellfish	*(102)*
Salmonellosis	Sewage-polluted water by untreated sewage (culture positive)	whitefish	*(63)*
Fascioliasis	Animal feces contaminated watercress bed	watercress	*(8)*
Viral hepatitis, gastroenteritis	Sewage-polluted water by cesspool	clams	*(44)*
Gastroenteritis	Sewage-polluted water[a]	clams	*(44)*
Salmonellosis (animal infection)	Animal dung slurry used to irrigate pastures	grass	*(87)*
Viral hepatitis	Sewage-polluted water[a]	clams	*(157)*
Fascioliasis	Animal feces contaminated water used for watercress beds	watercress	*(9)*

TABLE 8. *Continued.*

Cysticercosis (animal infection)	Sewage-contaminated irrigation water used for cattle watering	water	(*23*)
Ouch-ouch disease (cadmium poisoning)	Mining waste used to flood rice fields	rice	(*56*) (*98*)
Fascioliasis	Animal feces contaminated watercress bed	watercress	(*76*)
Viral hepatitis	Sewage-polluted water	clams	(*171*)
Cholera	Sewage-polluted water[a]	shellfish	(*55*)
Viral hepatitis	Septic tank effluent contaminated water[c]	watercress	(*85*)
Salmonellosis (animal infection, possible human cases)	Human sewage flowing over grazing land	grass	(*18*)
Viral hepatitis	Sewage-polluted water[a]	clams	(*16*)
Viral hepatitis	Sewage-polluted water[a]	oysters	(*116*) (*144*)
Cholera	Sewage-polluted water for growing and freshening	mussels	(*179*) (*11*)
Cholera El Tor	Night soil, raw sewage irrigation	vegetables	(*180*) (*36*)

[a]Implied
[b]Secondary treated sewage
[c]Primary treated sewage

Such outbreaks and source of contamination and vehicle for each are listed in Table 8. This table, which is obviously biased by incompleteness, shows that foods grown in water have been vehicles frequently. Shellfish which were contaminated in their growing area or during bloating after harvesting were vehicles in 28 outbreaks; watercress was the vehicle in 10 outbreaks; fish were vehicles in three outbreaks, and shrimp was the vehicle in one outbreak. Vegetables contaminated by night soil, human manure, or raw or partially treated sewage were reported as vehicles in 21 outbreaks. Fruits were considered vehicles in only four outbreaks. Before 1960, typhoid fever led the list of foodborne disease outbreaks attributed to wastewater contamination. The foods incriminated in these outbreaks were found to have been grossly contaminated with night soil or raw sewage. Outbreaks of infectious hepatitis are now reported most frequently, followed in frequency by outbreaks of fascioliasis and cholera. These findings reflect, in part, improvement in epidemiologic technique.

The epidemiologic evidence presented in many of the reports would not stand up to critical evaluation. On the other hand, a number of the investigators proved their hypotheses with epidemiologic and laboratory evidence. There are enough of these investigations to indicate that wastewater from mining, industrial, agricultural, community, and household sources have contaminated foods that, when eaten raw, have resulted in outbreaks of foodborne illness. These outbreaks will continue to occur sporadically if raw or partially treated wastewater is discharged into watercourses which are used for irrigation or aquaculture, and the contaminating pathogens survive in the wastewater, in soil, and then on contaminated foods in sufficient quantities.

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